Duluth Urban Area Streams Total Maximum Daily Load

Restoring and protecting urban streams in Duluth and surrounding areas.

MINNESOTA POLLUTION CONTROL AGENCY

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Acronyms and Abbreviations

AUID	assessment unit ID
BANCS	Bank Assessment for Nonpoint source Consequences of Sediment
BEHI	Bank Erosion Hazard Index
BMP	best management practice
CAFO	confined animal feeding operation
DNR	Minnesota Department of Natural Resources
DMR	discharge monitoring record
DUWAC	Duluth Urban Watershed Advisory Committee
E. coli	*Escherichia coli*
EPA	Environmental Protection Agency
EQuIS	Environmental Quality Information System
HSPF	Hydrologic Simulation Program–Fortran
HUC	Hydrologic Unit Code
ITPHS	imminent threat to public health and safety
LA	load allocation
LiDAR	Light Detection and Ranging
mg/L	milligrams per liter
mL	milliliters
MnDOT	Minnesota Department of Transportation
MOS	margin of safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
NBS	near bank stress
NPDES	National Pollutant Discharge Elimination System
NRRI	Natural Resources Research Institute
RSPT	Regional Stormwater Protection Team
SDS	State Disposal System
SWCD	soil and water conservation district
TMDL	Total Maximum Daily Load
TSS	total suspended solids
UMD	University of Minnesota Duluth
WARSSS	Watershed Assessment of River Stability and Sediment Supply
WLA	wasteload allocation
WRAPS	Watershed Restoration and Protection Strategy

Executive Summary

The Clean Water Act, Section 303(d) requires total maximum daily loads (TMDLs) to be developed for surface waters that do not meet applicable water quality standards necessary to support their designated uses. A TMDL determines the maximum amount of a pollutant a receiving water body can assimilate while still achieving water quality standards, and apportions load reductions among sources of pollutants. This TMDL study addresses stream impairments in the Duluth Urban Area in northeastern Minnesota. The Duluth Urban Area Streams TMDLs address a portion of the St. Louis River major watershed (Hydrologic Unit Code [HUC] 04010201) and a portion of the Lake Superior South Watershed (HUC 04010102), and includes all of the developed areas in the Duluth area and surrounding communities. Eleven stream TMDLs are provided, including seven *Escherichia coli* (*E. coli*) TMDLs and four total suspended solids (TSS) TMDLs. These TMDLs address aquatic recreation and aquatic life designated uses, respectively, and utilize real data collected in the watersheds and simulated data provided by a watershed model.

While development is prevalent in the Duluth Urban Area, natural land covers including forest and wetland form the majority of each of the impaired watersheds (51% to 89%). These natural areas are typically in the headwaters where slopes are low, and are shown to contribute negligibly to impairments. The watershed transitions to steep slopes and bedrock-controlled channels closer to Lake Superior. Streams in the southern part of the urban area (west in local parlance) meander through a large clay plain before discharging into the St. Louis River.

The high level of connected imperviousness relative to other North Shore watersheds contributes higher runoff volumes and peak flows to nearby streams. This altered flow contributes to near-channel erosion, defined as bluff and bank erosion, bank instability and channel scour. Potential sources of pollutants include watershed runoff (both regulated and unregulated), industrial wastewater, near-channel sources, failing septic systems and other sources of untreated wastewater, wildlife, and pets. Potential sources were identified through Minnesota Pollution Control Agency (MPCA) permit information and monitoring records, county and municipal records, watershed modeling studies, watershed and stream-specific studies and data, and field data.

The pollutant load capacity of the impaired streams was determined through the use of load duration curves. These curves represent the allowable pollutant load at any given flow condition. Water quality data were compared with the load duration curves to determine load reduction needs. A 10% explicit margin of safety (MOS) was incorporated into all TMDLs to account for uncertainty.

The overall implementation strategy highlights an adaptive management process to achieving water quality standards and restoring beneficial uses. It is also important to note that all efforts will also benefit drinking water source improvements and protection for area residents and other users. Implementation strategies include stormwater management and reducing connected imperviousness, industrial wastewater management, addressing sources of untreated wastewater (e.g., failing septic systems, leaky wastewater infrastructure, lack of restrooms in strategic locations), streambank restoration and stabilization, buffers, conservation and protection practices, and pet and wildlife waste management. An adaptive management approach may adjust implementation methods and locations of treatment, but the TMDL targets that represent the water quality standards do not change. The implementation approach will change in response to the level of progress towards the TMDL target.

A core team of local, state, and federal resource management agency staff supported the TMDL process and provided valuable input. The TMDL study is supported by previous work including the St. *Louis River Monitoring and Assessment Report* (MPCA 2013), *Lake Superior - South Monitoring and Assessment Report* (MPCA 2014), the *St. Louis River Watershed Stressor Identification* (MPCA 2016), the *Lake Superior - South Stressor Identification Report* (MPCA 2017a), and the *Revised Duluth Urban WRAPS HSPF Model report* (Tetra Tech 2019).

1. Project Overview

1.1 Purpose

The Clean Water Act and U.S. Environmental Protection Agency (EPA) regulations require that TMDLs be developed for waters not supporting their designated uses (e.g., propagation and maintenance of a healthy fish community and associated aquatic life and habitats, swimming). In simple terms, a TMDL is a study to determine how to attain and maintain water quality standards in waters that are not currently meeting them. This TMDL study addresses a portion of the St. Louis River major watershed (HUC 04010201) and a portion of the Lake Superior South Watershed (HUC 04010102) that include all of the developed areas in the Duluth area and surrounding communities (Figure 1) in St. Louis and Lake counties. The project area is approximately 141 square miles located in northeast Minnesota. In this report, the phrase "Duluth Urban Area Subwatershed" refers to the portion of the area bounded by Mission Creek in the southwest and the Lester River in the northeast.

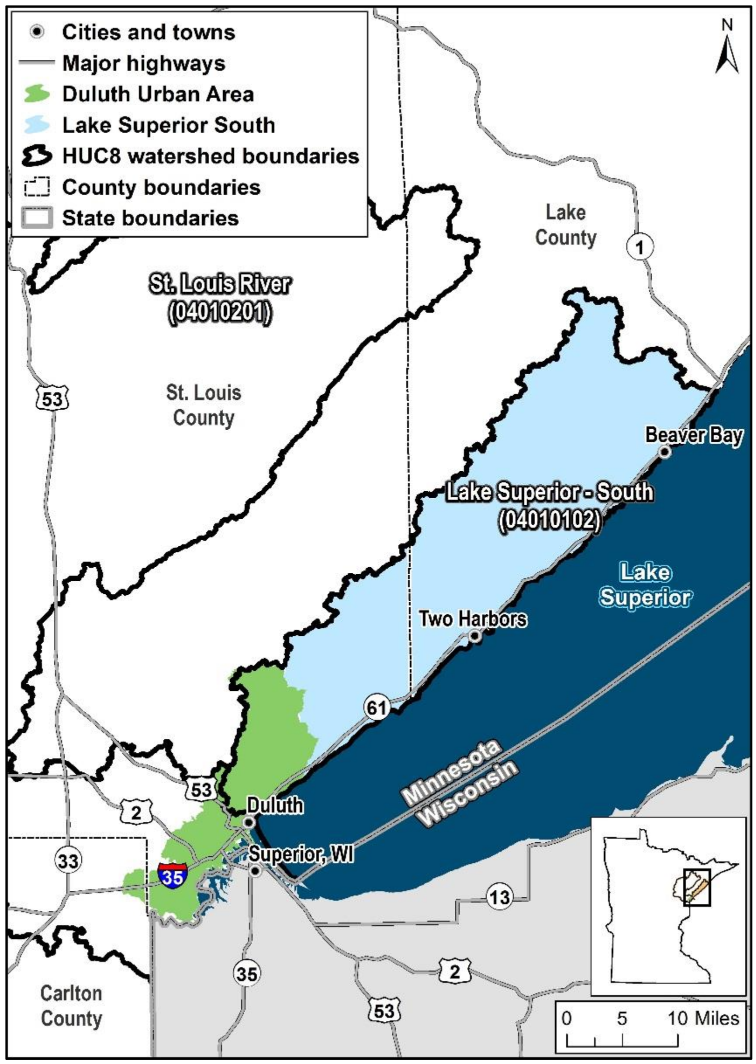


Figure 1. Duluth Urban Area Subwatershed.

This TMDL report is a component of a larger effort led by the MPCA to develop watershed restoration and protection strategies (WRAPS) for the Duluth Urban Area Subwatershed. Other components of this larger effort include the *St. Louis River Monitoring and Assessment Report* (MPCA 2013), *Lake Superior - South Monitoring and Assessment Report* (MPCA 2014), the *St. Louis River Watershed Stressor Identification* (MPCA 2016), the *Lake Superior - South Stressor Identification Report* (MPCA 2017a), the

Duluth Urban Watershed hydrology and water quality model (Tetra Tech 2019), and the Duluth Urban Area WRAPS Report.

There are many other ongoing efforts in the watershed to protect and improve water quality; these efforts involve citizens, civic organizations, businesses, and government organizations. For example, part of the St. Louis River Watershed is in the St. Louis River Area of Concern, designated under the United States and Canada Great Lakes Water Quality Agreement in 1987. The EPA and other federal and state agencies are working to remove beneficial use impairments due to legacy pollutants within the Area of Concern.

A bacterial source identification report, expected in 2020 for Tischer and Keene creeks, further explores sources of *E. coli* and site specific BMPs. (Burns & McDonnell Engineering Company, Inc. 2020). The more detailed stream reach investigative effort was contracted by the City of Duluth to better inform locations for specific BMP work. The investigative team used a weight of evidence method to gather information on numerous potential sources of *E. coli* in each of the two stream Study Areas. They applied a phased, tiered, and adaptive process that has been successful in identifying bacterial sources in urban streams (City of Minneapolis 2019; Goodwin et al. 2016; Griffith et al. 2013; Gruber et al. 2005). Best management practices are recommended for specific streambank erosional and degraded habitat areas, storm drain, storm sewer and wastewater infrastructure, and site specific city streets/public green space and other city owned properties. The detailed findings and suggested BMP recommendations of the study are an important supplement to the TMDL effort and the document may be found at web site https://www.pca.state.mn.us/water/duluth-urban-area-streams-watershed.

1.2 Identification of Water Bodies

This TMDL report addresses impairments in 11 stream reaches (Table 1 and Figure 2) in the Duluth Urban Area Subwatershed. The impairments affect aquatic life and aquatic recreation designated uses. All of the impairments are on the 2018 Clean Water Act, Section 303d list of impaired water bodies. Elevated temperatures in Miller Creek are addressed by a separate *Miller Creek Water Temperature Total Maximum Daily Load* (MPCA 2017b).

Several beaches are also listed as impaired for not supporting aquatic recreation due to high levels of *E. coli*. These beaches are being addressed through a separate TMDL process. The St. Louis River and Superior Bay are also identified as impaired for not supporting aquatic consumption; these impairments are due to high levels of toxins such as mercury and PCBs in fish tissue and in the water column, and are not addressed in this report. For more information on mercury impairments see the Statewide Mercury TMDL (MPCA 2007). The MPCA is developing a plan to address the remaining mercury impairments that do not qualify for inclusion in the Minnesota Statewide Mercury TMDL. Developing the TMDLs for mercury in the remaining impaired waters requires a better understanding of the watershed processes that convert inorganic mercury to methylmercury. The MPCA has completed some studies and continues working with the U.S. Geological Survey (USGS) as they study the effects of mercury and methylmercury loading in the St. Louis River Watershed. Follow postings and updates on the Statewide Mercury Reduction plan web page.

The turbidity standard used in previous Clean Water Act, Section 303d lists was replaced by TSS standards in 2015 (Minn. R. 7050.0222). Existing turbidity impairments will remain designated as turbidity impairments, but the TMDLs developed for them will be based on the TSS standards.

Table 1. Impaired waters (2018 Clean Water Act, Section 303d list of impaired water bodies)

Reach Name	AUID (04010xxx-xxx)	Use Class	Location/Reach Description	Affected Designated Use	Listing Year	Target Start/ Completion	Pollutant or Stressor
Keene Creek	201-627	2A	Headwaters to St Louis River	Aquatic Recreation	2012	2017/2019	*Escherichia coli*
Kingsbury Creek	201-626	2A	Mogie Lk to St Louis River	Aquatic Life	2012	2017/2019	Aquatic macroinvertebrate bioassessments
							Fishes bioassessments
Miller Creek	201-512	2A	Headwaters to St Louis River	Aquatic Life and Aquatic Recreation	2012	2016/2022	Aquatic macroinvertebrate bioassessments
					2010	2018/2022	Chloride
					2002	2016/2022	Lack of cold water assemblage
					2002	2016/2022	Temperature [a]
					2012	2017/2019	*Escherichia coli*
Sargent Creek	201-848	2A	Headwaters to St Louis River	Aquatic Recreation	2012	2017/2019	*Escherichia coli*
Stewart Creek	201-884	2A	T49 R15W S21, west line to St Louis River	Aquatic Recreation	2012	2017/2019	*Escherichia coli*
Unnamed creek (Merritt Creek)	201-987	2B	Unnamed creek to St Louis River	Aquatic Recreation	2012	2016/2022	*Escherichia coli*
Tischer Creek	102-544	2A	Unnamed creek to Lk Superior	Aquatic Recreation	2014	2017/2019	*Escherichia coli*
Chester Creek	102-545	2A	East Branch Chester Creek to Lake Superior	Aquatic Recreation	2014	2017/2019	*Escherichia coli*
Amity Creek	102-511	2A	Unnamed creek to Lester River	Aquatic Life	2004	2017/2019	Turbidity
Amity Creek, East Branch	102-540	2A	Unnamed creek to Amity Creek	Aquatic Life	2014	2017/2019	Turbidity
Lester River	102-549	2A	T52 R14W S23, north line to Lake Superior	Aquatic Life	1996	2017/2019	Turbidity

a. Impairment addressed by a separate TMDL *Miller Creek Water Temperature Total Maximum Daily Load* (MPCA 2017b).

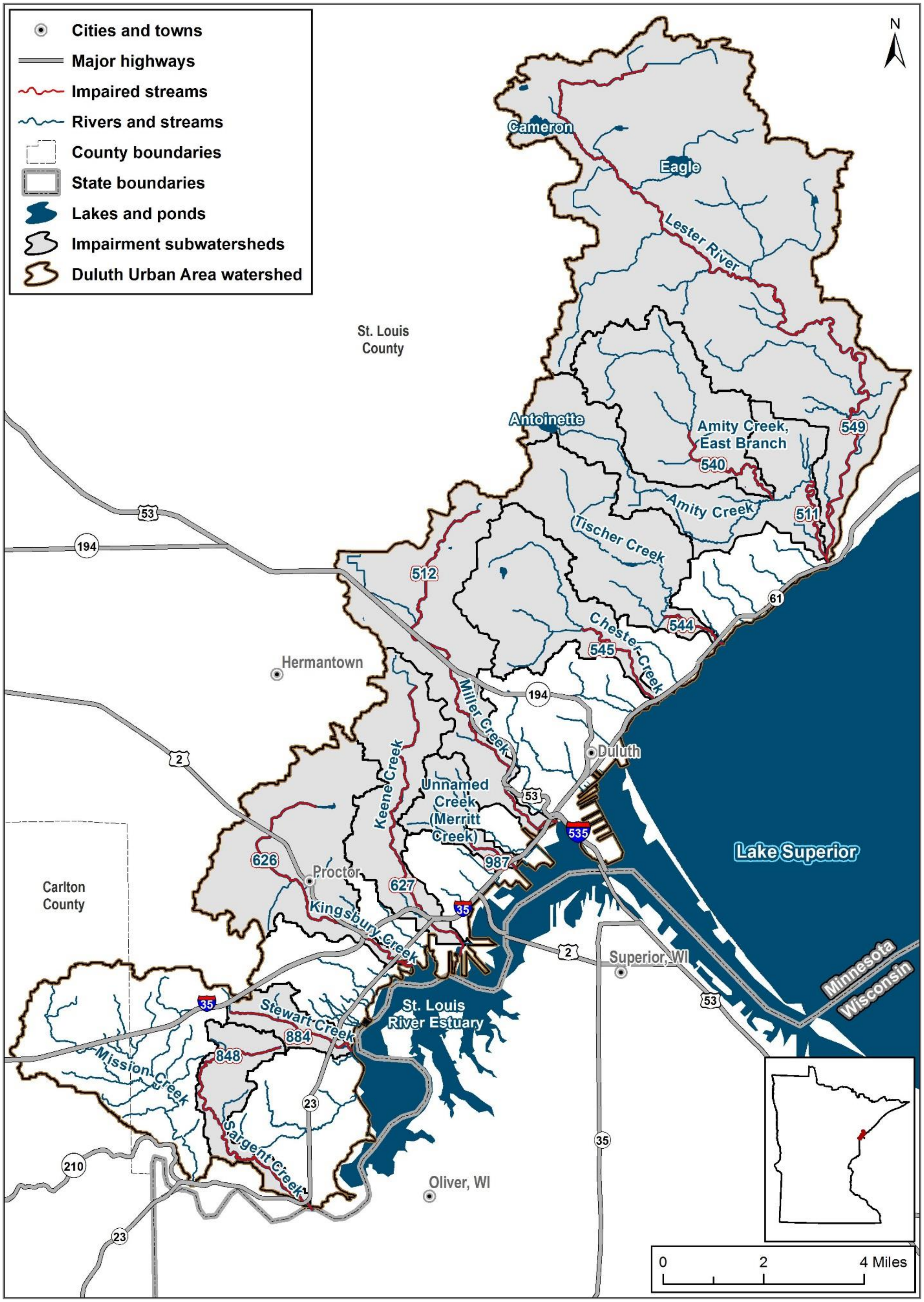


Figure 2. Duluth Urban Area stream impairments and subwatersheds (2018 303d list of impaired water bodies).

Biotic impairments (i.e., aquatic macroinvertebrates and fish community bioassessments) in Kingsbury Creek and Miller Creek were further evaluated for the cause of impairment as part of the stressor identification process (MPCA 2016). Table 2 summarizes the candidate causes evaluated for each biotic impaired stream. Biotic impairments are due to elevated water temperatures, low dissolved oxygen, elevated turbidity/TSS, chloride toxicity/specific conductivity, and poor physical habitat conditions.

Table 2. Summary of probable stressors to the biota impaired streams (MPCA 2016)

Candidate Cause	Kingsbury Creek	Miller Creek
Elevated Water Temperatures	•	•
Low Dissolved Oxygen	•	--
Total Suspended Solids / Turbidity	•	x
Chloride Toxicity / Specific Conductivity	○	•
Poor Physical Habitat Conditions	•	--
Copper and Lead Toxicity	○	--
Altered Hydrology	○	○

Key: • = confirmed stressor, ○ = potential stressor, X = eliminated candidate cause, -- = not evaluated

TMDLs are not developed for nonpollutant stressors, including poor physical habitat conditions. In addition, impairments in this subwatershed caused by elevated water temperatures and low dissolved oxygen are being deferred at this time to allow for additional investigation.

TSS/turbidity was confirmed as a stressor in Kingsbury Creek. The *St. Louis Stressor Identification* (MPCA 2016) report states that TSS concentrations frequently exceed the water quality standard, particularly during spring snowmelt and large rain events (MPCA 2016). Streambank and bluff erosion, unstable gully and ravine tributaries, and overland runoff from urban areas are all noted as contributing to high TSS concentrations in Kingsbury Creek (MPCA 2016). The study also determined that the amount of sediment being transported in the stream is limiting habitat for sensitive fish and macroinvertebrate taxa. Therefore, a TMDL was developed to address TSS/turbidity relative to the fish and macroinvertebrate impairment for Kingsbury Creek.

Specific to Miller Creek, TMDLs for the aquatic life impairments due to lack of cold water assemblage, macroinvertebrate bioassessments, and chloride are anticipated to be completed in the future, by approximately 2025. Table 3 summarizes the TMDLs being developed as part of this study.

Table 3. TMDL pollutants

Reach Name	AUID (04010xxx-xxx)	Location/Reach Description	Affected Designated Use Class	Pollutant or Stressor	TMDL Pollutant(s) Addressed in this Study
Keene Creek	201-627	Headwaters to St Louis River	Aquatic Recreation	*Escherichia coli*	*Escherichia coli*
Kingsbury Creek	201-626	Mogie Lake to St Louis River	Aquatic Life	Aquatic macroinvertebrate bioassessments	Total suspended solids
				Fishes bioassessments	
Miller Creek	201-512	Headwaters to St Louis River	Aquatic Life and Aquatic Recreation	Aquatic macroinvertebrate bioassessments [a]	*Escherichia coli*
				Chloride [a]	
				Lack of cold water assemblage [a]	
				Temperature [b]	
				Escherichia coli	
Sargent Creek	201-848	Headwaters to St Louis River	Aquatic Recreation	*Escherichia coli*	*Escherichia coli*
Stewart Creek	201-884	T49 R15W S21, west line to St Louis River	Aquatic Recreation	*Escherichia coli*	*Escherichia coli*
Unnamed creek (Merritt Creek)	201-987	Unnamed creek to St Louis River	Aquatic Recreation	*Escherichia coli*	*Escherichia coli*
Tischer Creek	102-544	Unnamed creek to Lake Superior	Aquatic Recreation	*Escherichia coli*	*Escherichia coli*
Chester Creek	102-545	East Br Chester Creek to Lake Superior	Aquatic Recreation	*Escherichia coli*	*Escherichia coli*
Amity Creek	102-511	Unnamed creek to Lester River	Aquatic Life	Turbidity	Total suspended solids
Amity Creek, East Branch	102-540	Unnamed creek to Amity Creek	Aquatic Life	Turbidity	Total suspended solids
Lester River	102-549	T52 R14W S23, north line to Lake Superior	Aquatic Life	Turbidity	Total suspended solids

a. TMDLs will be completed as part of a later cycle of work, by approximately 2025.

b. TMDL has been approved (MPCA 2017b).

1.3 Priority Ranking

The MPCA's schedule for TMDL completions, as indicated on the Clean Water Act, Section 303(d) impaired waters list, reflects Minnesota's priority ranking of this TMDL. The MPCA has aligned TMDL priorities with the watershed approach and WRAPS schedule. The MPCA developed a state plan, Minnesota's TMDL Priority Framework Report, to meet the needs of EPA's national measure (WQ-27) under EPA's Long-Term Vision for Assessment, Restoration and Protection under the Clean Water Act Section 303(d) Program. As part of these efforts, the MPCA identified water quality impaired segments that will be addressed by TMDLs by 2022. The Duluth Urban Area waters addressed by this TMDL are part of that MPCA prioritization plan to meet the EPA's national measure.

2. Applicable Water Quality Standards and Numeric Water Quality Targets

Water quality standards are designed to protect designated uses (see below for description). The standards consist of the designated uses, criteria to protect the uses, and other provisions such as antidegradation policies that are designed to protect existing uses or qualities of a particular water body.

2.1 Designated Uses

Use classifications are defined in Minn. R. 7050.0140, and water use classifications for individual water bodies are provided in Minn. R. 7050.0470, 7050.0425, and 7050.0430. This TMDL report addresses the water bodies that do not meet the standards for Class 2 waters, which are protected for aquatic life and recreation designated uses. All of the impaired streams in this report are classified as Class 2A or 2B waters.

Class 2A waters are protected for the propagation and maintenance of a healthy community of cold water sport or commercial fish and associated aquatic life and their habitats. Class 2B waters are protected for the propagation and maintenance of a healthy community of cool or warm water sport or commercial fish and associated aquatic life and their habitats. Both Class 2A and 2B waters are also protected for aquatic recreation activities including bathing and swimming.

2.2 Water Quality Criteria

Water quality criteria for Class 2 waters are defined in Minn. R. 7050.0222. The pollutants addressed in this TMDL are *E. coli* and TSS. In Minnesota, *E. coli* is used as an indicator species of potential water pathogens, and exceedances of the *E. coli* criteria indicate that a water body does not meet the aquatic recreation designated use. Table 4 summarizes the criteria and the TMDL endpoints.

Table 4. Water quality criteria for *E. coli* and TSS in streams

Water Body Type	Parameter	Water Quality Criteria	TMDL Endpoint
Class 2 (A and B) streams	*Escherichia coli*	Not to exceed 126 organisms per 100 mL as a geometric mean of not less than five samples representative of conditions within any calendar month, nor shall more than 10% of all samples taken during any calendar month individually exceed 1,260 organisms per 100 milliliters. The standard applies only between April 1 and October 31.	< 126 organisms / 100 mL water (monthly geometric mean) < 1,260 organisms / 100 mL water (individual sample)
Class 2A streams	TSS [a]	10 mg/L; TSS standards for Class 2A may be exceeded for no more than 10% of the time. This standard applies April 1 through September 30.	< 10 mg/L TSS

a. A previous turbidity standard was replaced by the TSS standard in 2015. The previous turbidity standard for Class 2A surface waters was 10 nephelometric turbidity units for protection of aquatic life.

3. Watershed and Water Body Characterization

Monitoring and assessment reports for the St. Louis River (MPCA 2013) and Lake Superior South (MPCA 2014) watersheds provide a description of the watershed, including discussions of ecoregions, soils, land cover, surface hydrology, precipitation trends, hydrogeology, groundwater quality, and wetlands. Much of the information provided below is extracted from the reports. See the reports for additional details if needed.

3.1 Subwatersheds

Subwatersheds that drain to impaired waters range in size from 1,108 acres to 34,240 acres (Table 5 and Figure 2). Subwatershed boundaries are based on catchments delineated during creation of a Hydrologic Simulation Program–FORTRAN (HSPF) model application in the Duluth Urban Area (Tetra Tech 2019). Appendix A includes the full HSPF model report completed in 2019; Table 5 includes impaired stream assessment unit IDs (AUIDs) and applicable model reaches. HSPF model catchments are based on storm sewer catchments from the City of Duluth and stormwater information from the City of Hermantown, Minnesota Department of Natural Resources (DNR) Level 8 and 9 catchments and available Light Detection and Ranging (LiDAR) elevation data. (Minnesota Information Technology. Minnesota Elevation Mapping Project. Available online at: http://www.mngeo.state.mn.us/chouse/elevation/lidar.html.)

Amity Creek and East Branch Amity Creek are nested within the Lester River impairment subwatershed. The subwatershed area includes all drainage area to the impairment, including upstream assessment units.

Table 5. Impairment subwatershed areas and model reaches

Impaired Reach Name	Assessment Unit (04010xxx-xxx)	Subwatershed Area (acres)	Upstream Assessment Unit(s) (04010xxx-xxx)	Model Reach(es)
Amity Creek	102-511	10,568	102-540	435
Amity Creek, East Branch	102-540	5,237	-	454
Chester Creek	102-545	4,315	-	385
Keene Creek	201-627	4,029	-	302
Kingsbury Creek	201-626	6,012	-	272
Lester River	102-549	34,240	102-511, 102-540	435 + 483
Miller Creek	201-512	6,212	-	330
Sargent Creek	201-848	1,964	-	232
Stewart Creek	201-884	1,108	-	247
Tischer Creek	102-544	4,767	-	406
Unnamed creek (Merritt Creek)	201-987	1,412	-	320

3.2 Land Cover

The Duluth Urban Area Streams Subwatershed is in northeastern Minnesota in the Lake Superior Basin in the Northern Lakes and Forests ecoregion. Land cover for the Duluth Urban Area Subwatershed is presented in Figure 3; these data are based on the 2013 Minnesota Land Cover Classification. The dominant land cover in the impairment subwatersheds is deciduous forest (Table 6). Various levels of urban development, conifer forest, and forested and shrub wetlands make up the majority of the remaining land. Urban development is highest in the central portion of the watershed in the Miller Creek Subwatershed and decreases toward the northern (Lester River) and southern extent (Mission Creek) of the watershed.

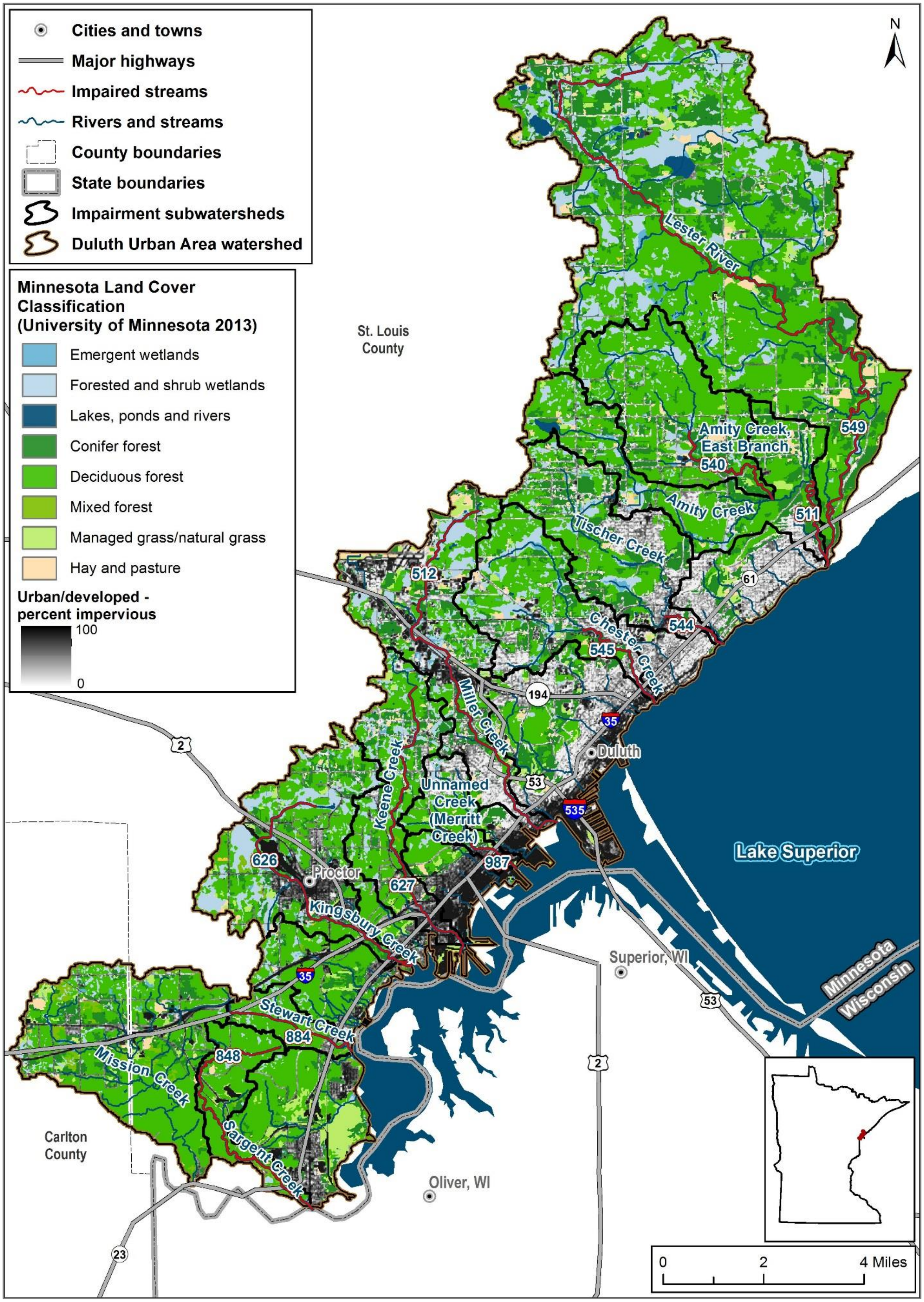


Figure 3. Land use and land cover in the Duluth Urban Area.

Table 6. Land cover/land use (source: University of Minnesota 2013)
Percent rounded to nearest whole number.

Water Body Name (AUID)	Watershed Areas	Percent of Watershed (%)													
		Natural Land Covers								Developed/Disturbed Land Covers					
		Deciduous Forest	Conifer Forest	Mixed Forest	Managed/Natural Grass	Forested and Shrub Wetlands	Emergent Wetlands	Lakes, Ponds, and Rivers	*Total Natural Land Cover*	Hay and Pasture	0 – 25% Impervious	26 – 50% Impervious	51 – 75% Impervious	76 – 100% Impervious	*Developed/Disturbed Land Cover*
Amity Creek (04010102-511)	10,568	55	17	0	2	8	1	1	*84*	3	7	5	1	0	*16*
Chester Creek (04010102-545)	4,315	37	15	0	1	14	3	0	*70*	2	13	9	4	2	*30*
E Br Amity Creek (04010102-540)	5,237	59	15	0	2	9	2	1	*88*	2	5	4	1	0	*12*
Keene Creek (04010201-627)	4,029	39	14	0	2	13	2	1	*71*	2	7	8	7	5	*29*
Kingsbury Creek (04010201-626)	6,012	35	11	1	2	20	1	1	*71*	2	3	6	9	9	*29*
Lester River (04010102-549)	34,240	48	20	0	2	15	2	2	*89*	3	4	3	1	0	*11*
Merritt Creek (04010201-987)	1,412	42	11	0	4	7	0	0	*64*	1	13	8	6	8	*36*
Miller Creek (04010201-512)	6,212	19	14	0	2	13	2	1	*51*	4	15	11	9	10	*49*
Sargent Creek (04010201-848)	1,964	73	3	6	3	4	0	0	*89*	1	1	3	3	3	*11*
Stewart Creek (04010201-884)	1,108	74	2	2	0	9	1	0	*88*	0	3	5	3	1	*12*
Tischer Creek (04010102-544)	4,767	28	23	0	1	8	2	1	*63*	2	18	12	4	1	*37*

3.3 Current/Historic Water Quality

The *Lake Superior South Monitoring and Assessment Report* (MPCA 2014) and *St. Louis River Watershed Monitoring and Assessment Report* (MPCA 2013) contain figures and tables that summarize water quality data on a HUC-10 basis and address habitat, channel condition and stability, and water chemistry. The *Lake Superior South Watershed Stressor Identification Report* (MPCA 2017a) and *St. Louis River Watershed Stressor Identification Report* (MPCA 2016) include evaluation of fish, macroinvertebrates, flow alteration, habitat, and water chemistry data for streams with biotic impairments (i.e., Kingsbury Creek and Miller Creek).

Water quality monitoring stations along the impaired reaches are presented in Figure 4 through Figure 6. The assessment of current and historic water quality is based primarily on data from the MPCA's Environmental Quality Information System (EQuIS database, received February 6, 2017, from MPCA staff). Monitoring data from all sites along an impaired segment were aggregated and presented together. Water quality data from 2007 to 2016 were summarized for TSS and *E. coli,* by year to evaluate trends in water quality, and by month to evaluate seasonal variation. The summaries of data by year only consider data during the time period that the standard is in effect (April through September for TSS and April through October for *E. coli*). The frequency of exceedances represents the percentage of samples that do not meet the water quality standard. Exceedances of the TSS and *E. coli* standards are highlighted under the following conditions in the water quality summary tables: (1) the frequency of exceedance of the TSS standard is greater than 10% (monthly and yearly summary tables), (2) the monthly *E. coli* geometric mean is greater than the standard (126 org / 100 mL), and (3) the frequency of exceedance of the *E. coli* individual sample standard (1,260 organisms / 100 mL) is greater than 10% (monthly summary tables).

Water quality duration curves are provided for the reaches with TSS and *E. coli* data, and are used to evaluate the relationships between hydrology and water quality because water quality is often a function of stream flow. For example, sediment concentrations typically increase with rising flows as a result of factors such as channel scour from higher velocities and volumes. Other parameters may be more concentrated at low flows and diluted by increased water volumes at higher flows. The water quality duration curve approach provides a visual display of the relationship between stream flow and water quality. Water quality duration curves are provided using water quality monitoring data and simulated daily average stream flow from the Duluth Urban Area HSPF model (Tetra Tech 2019). Flow data from all months are plotted in the water quality duration figures.

The Duluth Urban Area HSPF model was calibrated for hydrology at seven stations in the watershed, including three on Miller Creek and one each on Amity Creek, Tischer Creek, Kingsbury Creek, and Lester River. These stations provided the longest record of measurements. The model was then validated at eight different sites (Keene Creek, Merritt Creek, Chester Creek, Mission Creek, Tischer Creek, East Branch Amity Creek, and two sites on Miller Creek). Keene Creek, Merritt Creek, Chester Creek, Mission Creek, Tischer Creek, and a new site on Miller Creek provided two field seasons of monitoring data. Calibration and validation was completed by comparing time-series daily average model results to gaged daily average flow. Key considerations in the hydrology calibration were the overall water balance, the high-flow to low-flow distribution, storm flows, and seasonal variations. See Appendix A for full model documentation. The models were determined to be sufficient for TMDL development.

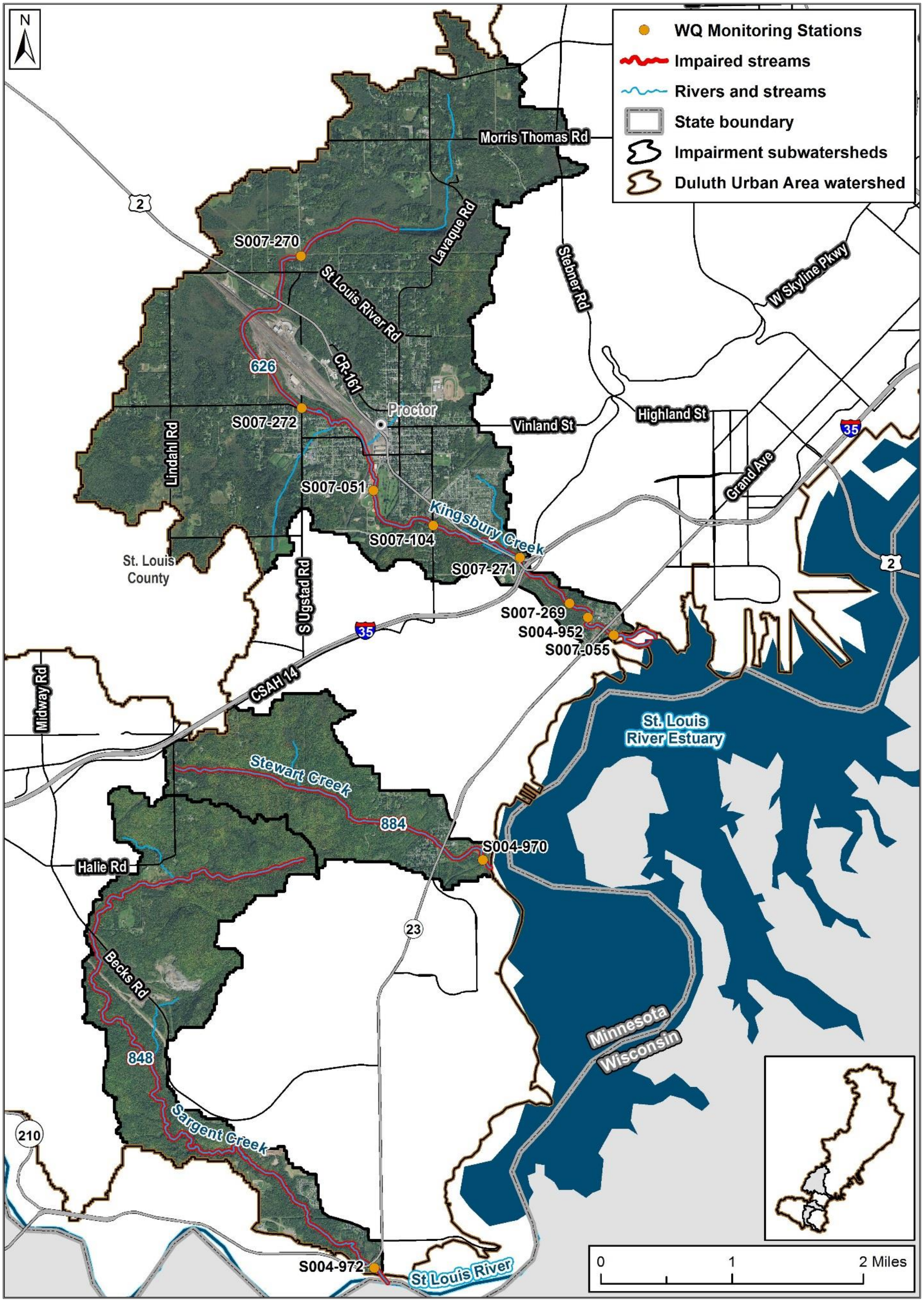


Figure 4. Water quality monitoring locations within the Kingsbury Creek, Stewart Creek, and Sargent Creek subwatersheds.

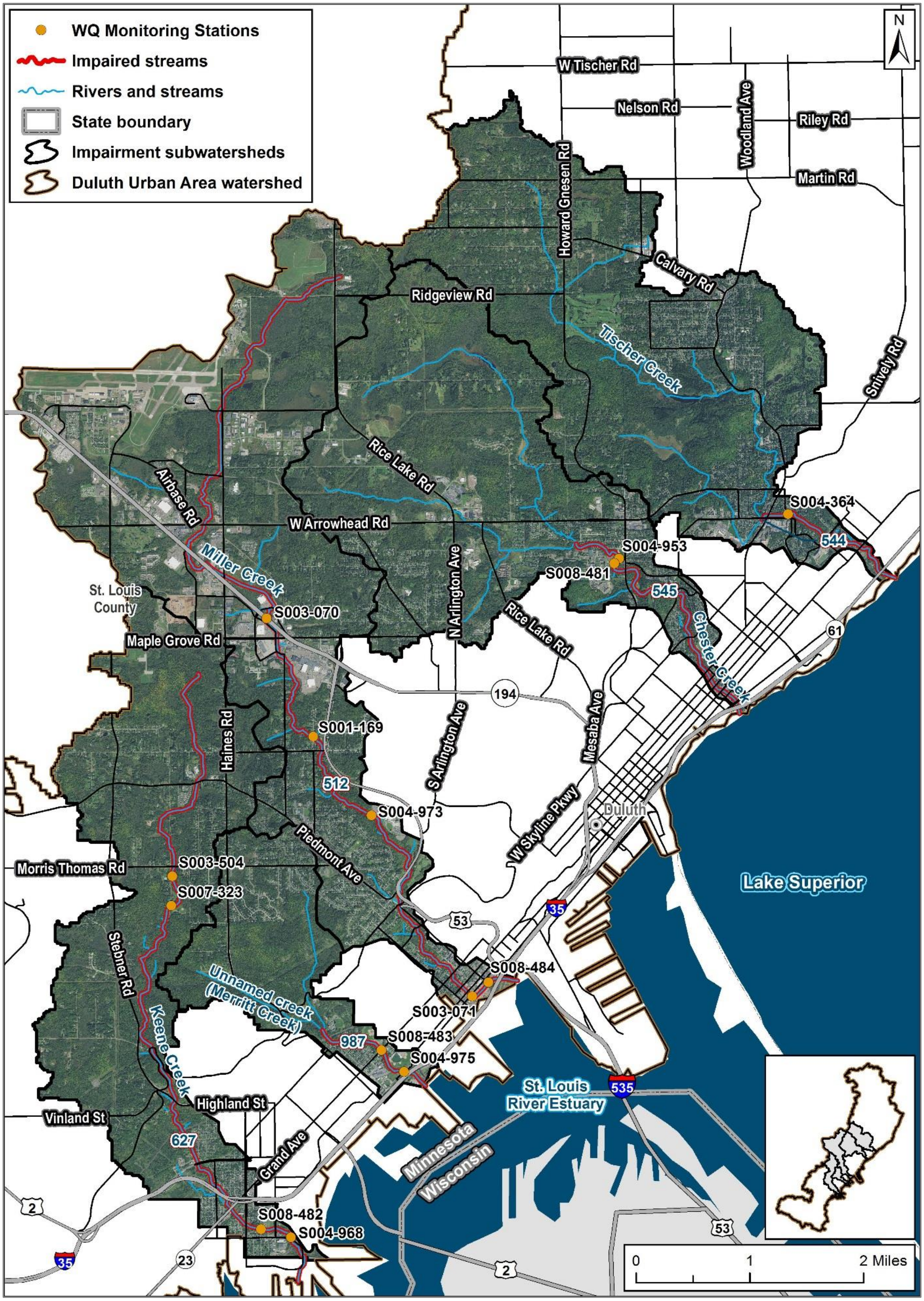


Figure 5. Water quality monitoring locations within the Tischer Creek, Chester Creek, Miller Creek, Unnamed creek (Merritt Creek), and Keene Creek subwatersheds.

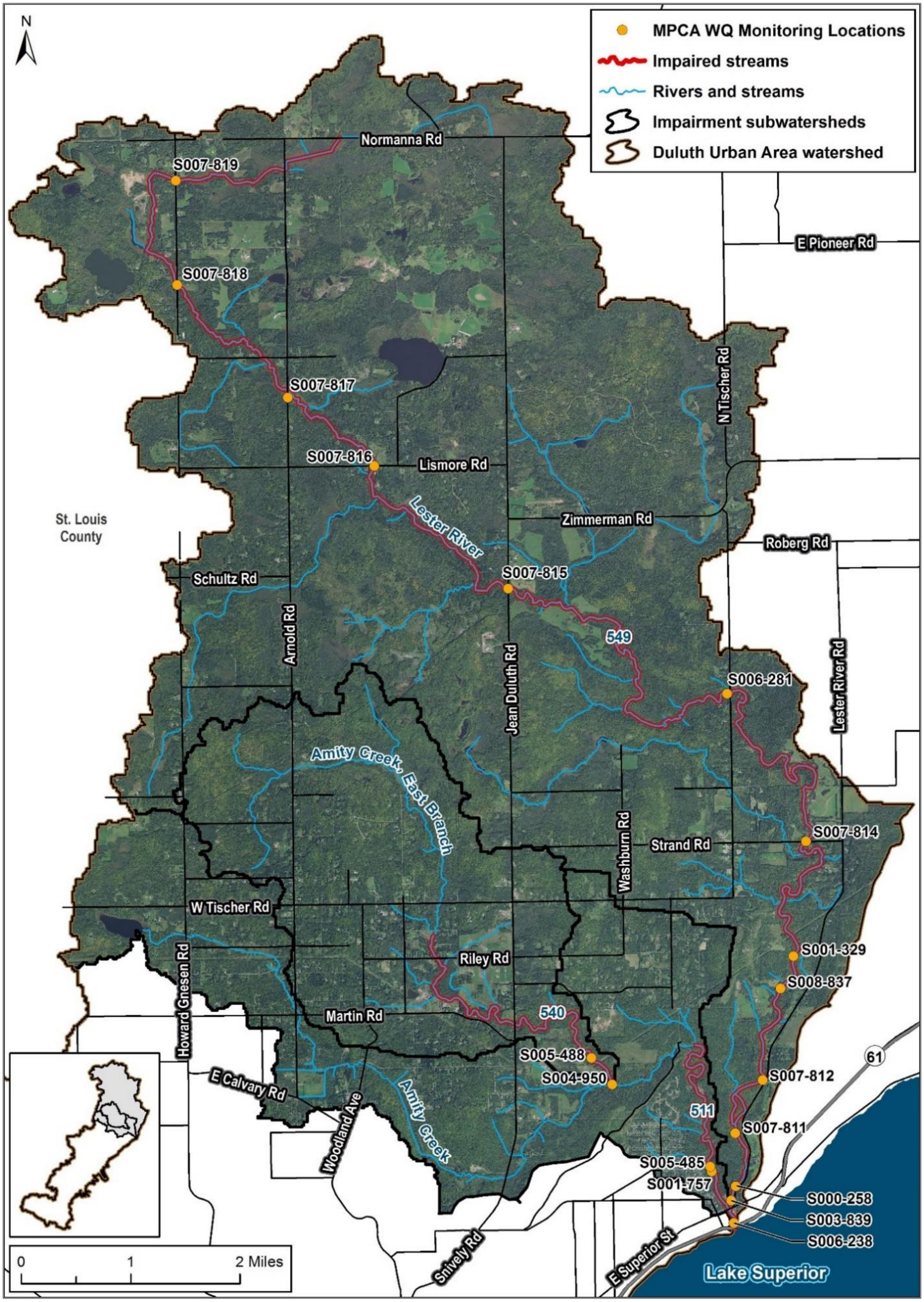


Figure 6. Water quality monitoring locations within the Lester River, Amity Creek, and East Branch Amity Creek subwatersheds.

3.3.1 Keene Creek (04010201-627) *E. coli*

There are two monitoring stations on Keene Creek (Figure 5). The *E. coli* concentration exceeded the individual sample standard in one or more samples in four of the five monitored years (Table 7). Exceedances of the monthly geometric mean standard were observed from June through September, and concentrations on average were highest in August and September (Table 8). Exceedances were observed under all flows except very low flow conditions. Most exceedances occurred under very high and high flows (Figure 7).

Table 7. Annual Summary of *E. coli* data for Keene Creek.
(AUID 04010201-627, sites S004-968 and S008-482, Apr–Oct)

Year	Sample Count	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	Number of Individual Sample Standard Exceedances (>1,260 org/100 mL)	Percent of Individual Sample Standard Exceedances (%)
2008	6	34	0.5	365	0	0
2009	7	742	121	≥2,420[a]	2	29
2010	2	1,403	820	2,400	1	50
2015	20	637	47	2,400	11	55
2016	12	1,060	133	≥2,420[a]	7	58

a. 2,420 org/100mL is the method's maximum recordable value

Table 8. Monthly Summary of *E. coli* data for Keene Creek.
(AUID 04010201-627, sites S004-968 and S008-482; 2008–2010, 2015–2016). Values in red indicate months in which the monthly geometric mean standard of 126 org/100 mL was exceeded or the individual sample standard of 1,260 org/100 mL was exceeded in greater than 10% of the samples.

Month	Sample Count	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	Number of Individual Sample Standard Exceedances (>1,260 org/100 mL)	Percent of Individual Sample Standard Exceedances (%)
March	2	10	1	110	NA	NA
April	2[a]	72	59	87	0	0
May	3[a]	152	47	1,100	0	0
June	10	595	18	≥2,420[b]	4	40
July	12	499	0.5	≥2,420[b]	5	42
August	12	961	24	≥2,420[b]	8	67
September	6	944	133	2,400	4	67
October	2[a]	98	56	170	0	0

a. Not enough samples to assess compliance with the monthly geometric mean standard
b. 2,420 org/100mL is the method's maximum recordable value
NA: not applicable because the *E. coli* standard does not apply during this month

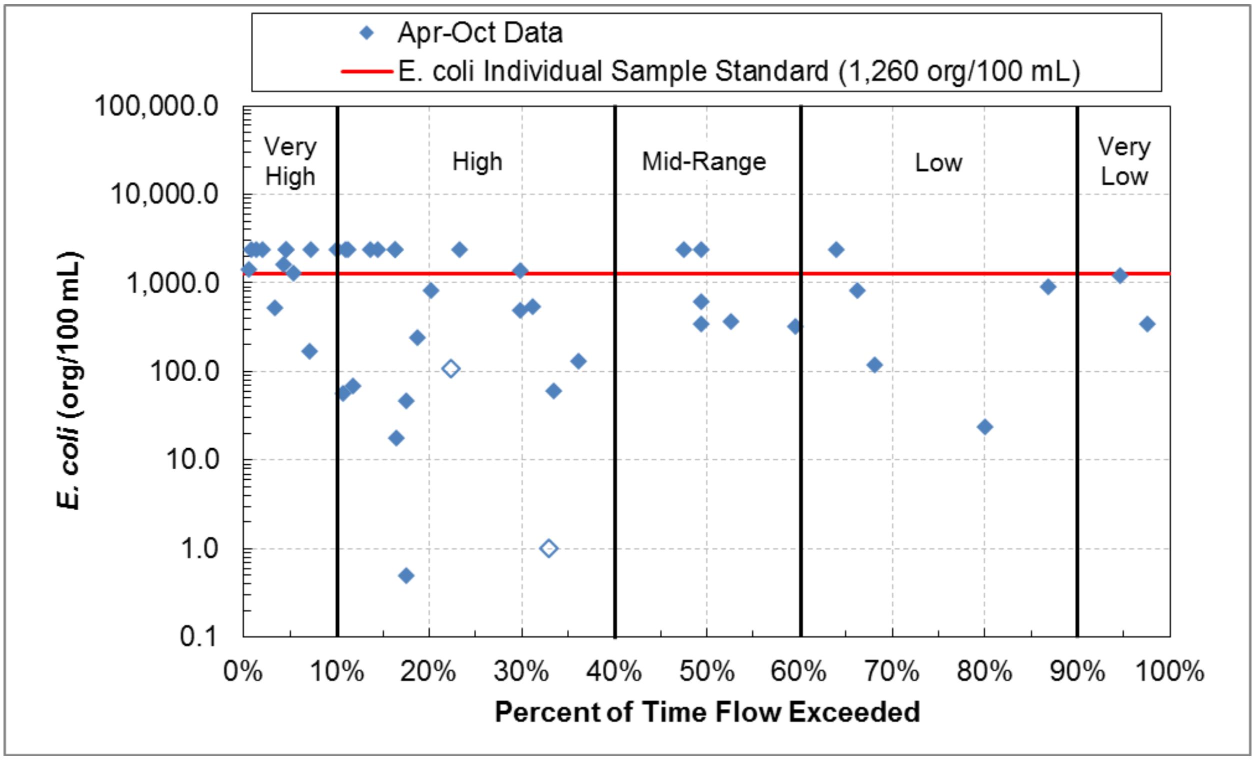


Figure 7. *E. coli* water quality duration plot, Keene Creek.
(AUID 04010201-627), 2008–2010, 2015–2016. Hollow points indicate samples during months when the standard does not apply.

3.3.2 Kingsbury Creek (04010201-626) Total Suspended Solids

There are eight monitoring stations on Kingsbury Creek (Figure 4). Average annual TSS concentrations in Kingsbury Creek ranged from 12 to 101 milligrams per liter (mg/L), and greater than 10% of samples exceeded the 10 mg/L TSS standard in each year that was monitored (Table 9). Monthly means (during the months in which the standard applies) varied from 33 to 839 mg/L, with the highest concentrations on average observed in April (Table 10). The standard was exceeded during mid-range to very high flows, with higher concentrations occurring under very high flows (Figure 8).

The *St. Louis Stressor Identification* (MPCA 2016) report provides the following summary of longitudinal TSS conditions in Kingsbury Creek:

> Kingsbury data was lumped into three reaches due to the small number of samples at some sites. The three reaches are: 1) the upper watershed upstream of Boundary Avenue, 2) the transitional zone between Boundary Avenue and Interstate 35, and 3) the bedrock-dominated escarpment downstream of Interstate 35. The TSS and Secchi tube datasets for Kingsbury show a clear longitudinal trend, with a consistent violation of the draft standards in the transitional zone between Boundary Ave and Interstate 35. This reach contains many eroding banks and is where the unnamed tributary discussed above enters Kingsbury Creek. TSS and Secchi tube data show improving water quality downstream of the Interstate – most likely due to the bedrock- and boulder-dominated channel and the influence of clear groundwater seepage into the stream in this reach.

The Stressor Identification Report (MPCA 2016) also states the following:

> ... a significant amount of sediment is also being introduced from the main stem Kingsbury Creek segment between Boundary Avenue and Skyline Parkway.

Table 9. Annual Summary of TSS data for Kingsbury Creek.
(AUID 04010102-626, sites S004-952, S007-051, S007-055, S007-104, S007-269, S007-270, S007-271 and S007-272, Apr–Sep). Values in red indicate years in which the numeric criteria of 10 mg/L was exceeded in greater than 10% of the samples.

Year	Sample Count	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Number of Exceedances	Frequency of Exceedances
2008	14	12	1	38	6	43%
2009	3	7	2	13	1	33%
2010	9	53	4	206	7	78%
2012	5	26	2	84	3	60%
2014	7	101	4	240	5	71%

Table 10. Monthly Summary of TSS data for Kingsbury Creek.
(AUID 04010102-626, sites S004-952, S007-051, S007-055, S007-104, S007-269, S007-270, S007-271 and S007-272; 2008–2010, 2012, 2014). Values in red indicate months in which the numeric criteria of 10 mg/L was exceeded in greater than 10% of the samples.

Month	Sample Count	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Number of Exceedances	Frequency of Exceedances
March	7	17	3	43	NA	NA
April	17	49	2	240	10	59%
May	7	48	1	206	4	57%
June	5	16	2	34	2	40%
July	3	60	1	166	2	67%
August	3	14	10	16	2	67%
September	3	11	4	17	2	67%
October	1	88	88	88	NA	NA

NA: not applicable because the TSS standard does not apply during this month

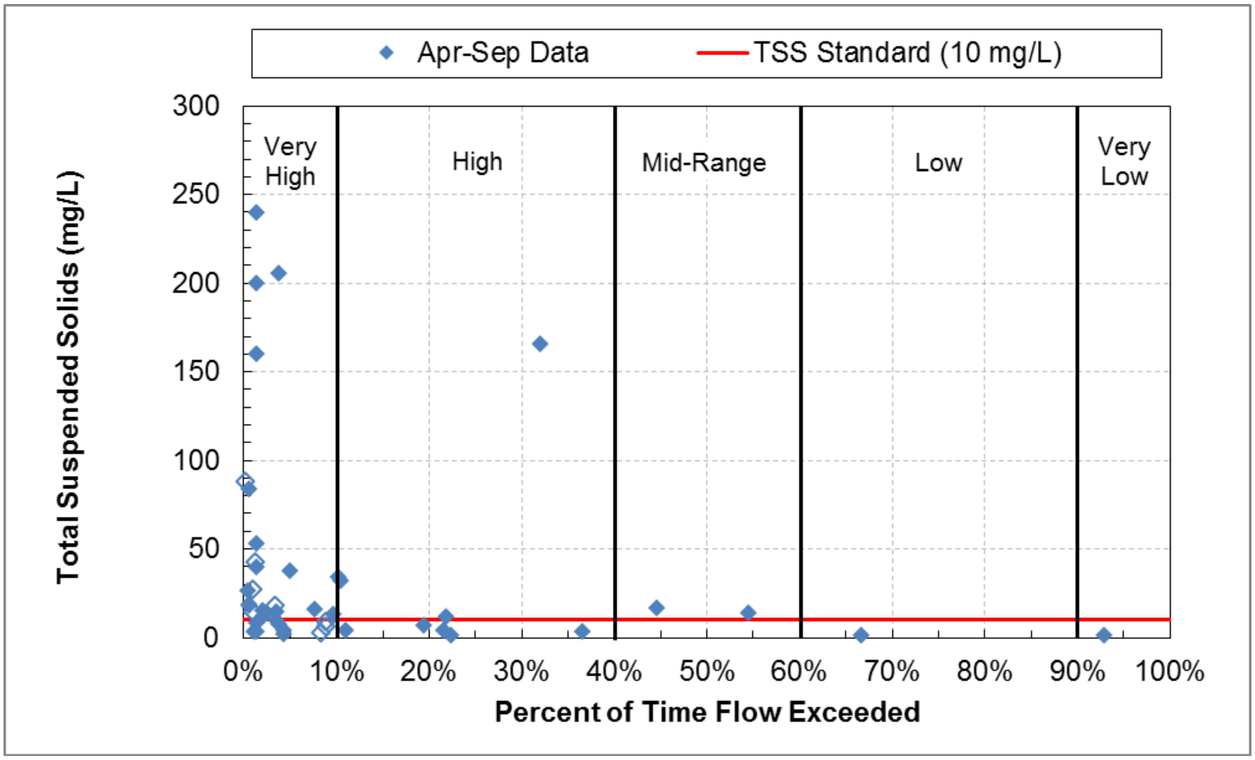


Figure 8. TSS water quality duration plot, Kingsbury Creek.
(AUID 04010201-626), 2008–2010, 2012, 2014. Hollow points indicate samples during months when the standard does not apply.

3.3.3 Miller Creek (04010201-512) *E. coli*

There are five monitoring stations on Miller Creek (Figure 5). The *E. coli* concentration exceeded the individual sample standard in one or more samples in four of the five monitored years (Table 11). Exceedances of the monthly geometric mean standard were observed in June through September, and concentrations on average were highest in July (Table 12). The individual sample standard was exceeded during mid-range to very high flows, with higher concentrations occurring under high and very high flows (Figure 9).

Table 11. Annual Summary of *E. coli* data for Miller Creek.
(AUID 04010201-512, sites S001-169, S003-070, S003-071, S004-973 and S008-484, Apr–Oct)

Year	Sample Count	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	Number of Individual Sample Standard Exceedances (>1,260 org/100 mL)	Percent of Individual Sample Standard Exceedances (%)
2008	22	116	21	1,046	0	0
2009	32	237	46	1,733	3	9
2010	11	186	68	2,400	1	9
2015	20	829	67	2,400	10	50
2016	12	723	56	≥2,420[a]	6	50

a. 2,420 org/100mL is the method's maximum recordable value

Table 12. Monthly Summary of *E. coli* data for Miller Creek.

(AUID 04010201-512, sites S001-169, S003-070, S003-071, S004-973 and S008-484; 2008–2010, 2015–2016). Values in red indicate months in which the monthly geometric mean standard of 126 org/100 mL was exceeded or the individual sample standard of 1,260 org/100 mL was exceeded in greater than 10% of the samples.

Month	Sample Count	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	Number of Individual Sample Standard Exceedances (>1,260 org/100 mL)	Percent of Individual Sample Standard Exceedances (%)
March	2	53	13	220	NA	NA
April	2[a]	176	67	460	0	0
May	3[a]	304	96	1,400	1	33
June	23	196	26	≥2,420[b]	5	22
July	28	418	46	≥2,420[b]	6	21
August	29	275	21	≥2,420[b]	4	14
September	10	305	27	2,400	4	40
October	2[a]	535	260	1,100	0	0

a. Not enough samples to assess compliance with the monthly geometric mean standard

b. 2,420 org/100mL is the method's maximum recordable value

NA: not applicable because the *E. coli* standard does not apply during this month

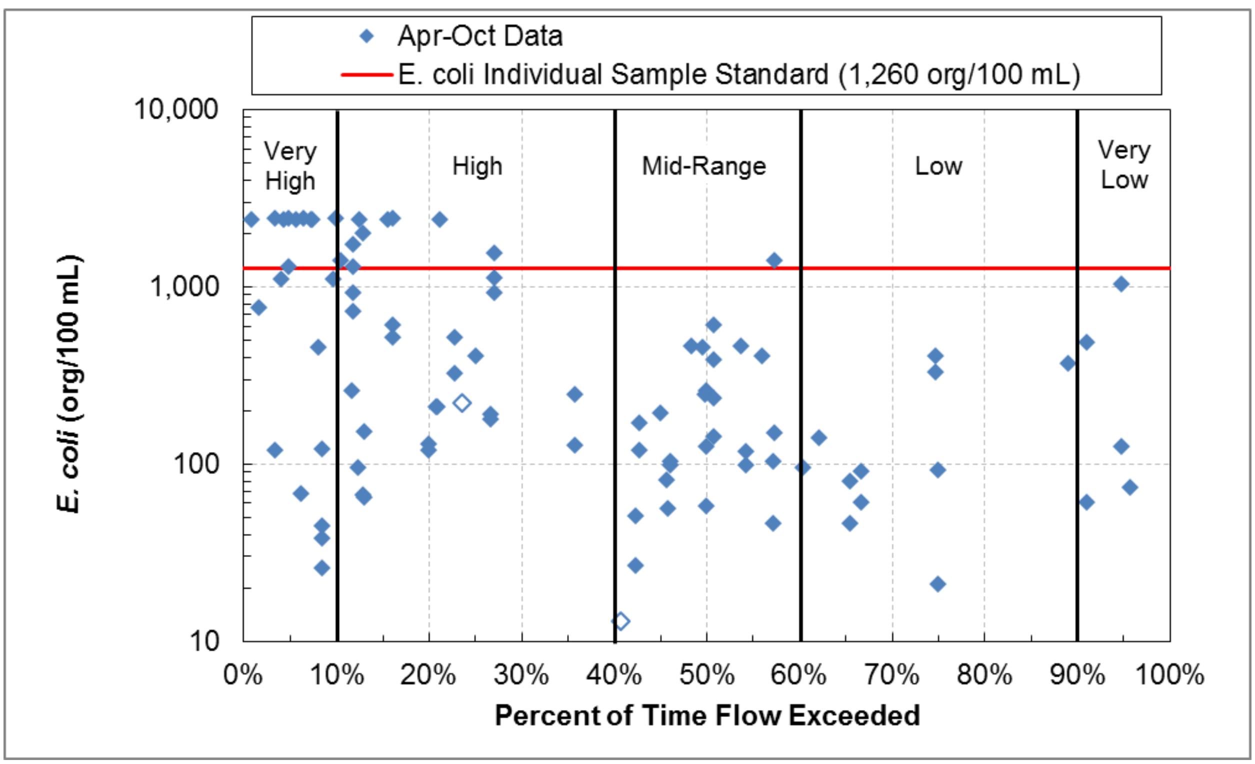


Figure 9. *E. coli* water quality duration plot, Miller Creek.

(AUID 04010201-512), 2008–2010, 2015–2016. Hollow points indicate samples during months when the standard does not apply.

3.3.4 Sargent Creek (04010201-848) *E. coli*

There is one monitoring station located at the downstream end of Sargent Creek (Figure 4). Two samples exceeded the individual sample standard in 2009 (Table 13), and the monthly geometric mean standard was exceeded in June through August (Table 14). Both exceedances occurred under mid-range flow conditions. No samples were collected during very high flow conditions (Figure 10).

Table 13. Annual Summary of *E. coli* data for Sargent Creek.
(AUID 04010201-848, site S004-972, Apr–Oct)

Year	Sample Count	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	Number of Individual Sample Standard Exceedances (>1,260 org/100 mL)	Percent of Individual Sample Standard Exceedances (%)
2008	3	129	35	1,203	0	0
2009	8	193	23	≥2,420[a]	2	25
2010	5	325	170	1,200	0	0

a. 2,420 org/100mL is the method's maximum recordable value

Table 14. Monthly Summary of *E. coli* data for Sargent Creek.
(AUID 04010201-848, site S004-972; 2008–2010). Values in red indicate months in which the monthly geometric mean standard of 126 org/100 mL was exceeded or the individual sample standard of 1,260 org/100 mL was exceeded in greater than 10% of the samples.

Month	Sample Count	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	Number of Individual Sample Standard Exceedances (>1,260 org/100 mL)	Percent of Individual Sample Standard Exceedances (%)
June	5	228	58	1,200	0	0
July	5	143	23	≥2,420[b]	1	20
August	5	203	35	≥2,420[b]	1	20
September	1[a]	1,203	1,203	1,203	0	0

a. Not enough samples to assess compliance with the monthly geometric mean standard
b. 2,420 org/100mL is the method's maximum recordable value

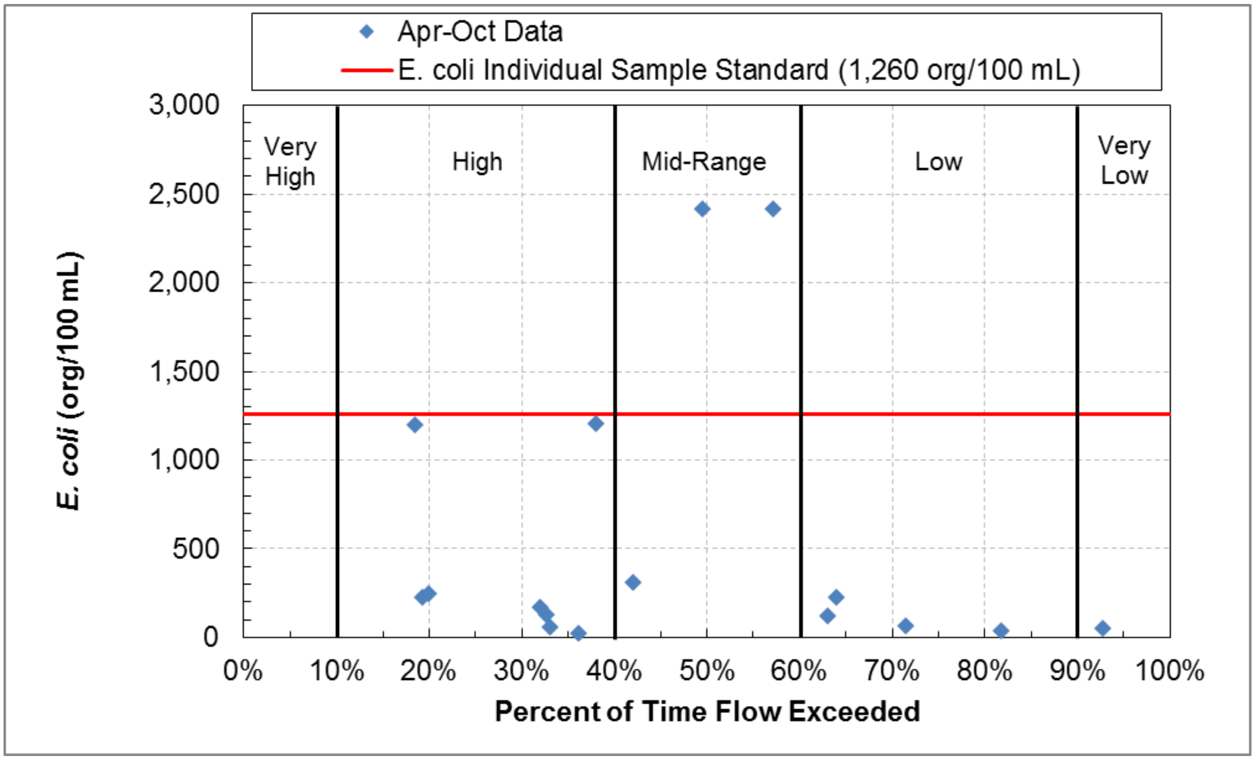


Figure 10. *E. coli* water quality duration plot, Sargent Creek.
(AUID 04010201-848), 2008–2010

3.3.5 Stewart Creek (04010201-884) *E. coli*

There is one monitoring station located at the downstream end of Stewart Creek (Figure 4). Exceedances of the individual sample standard were not observed (Table 15). The monthly geometric mean standard was exceeded during the month of July (Table 16). *E. coli* concentrations were highest under high and midrange flows. No samples were collected during very high flow conditions (Figure 11).

Table 15. Annual Summary of *E. coli* data for Stewart Creek.
(AUID 04010201-884, site S004-970, Apr–Oct)

Year	Sample Count	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	Number of Individual Sample Standard Exceedances (>1,260 org/100 mL)	Percent of Individual Sample Standard Exceedances (%)
2008	3	64	45	88	0	0
2009	8	143	34	866	0	0
2010	5	105	19	580	0	0

a. 2,420 org/100mL is the method's maximum recordable value

Table 16. Monthly Summary of *E. coli* data for Stewart Creek.
(AUID 04010201-884, site S004-970; 2008–2010). Values in red indicate months in which the monthly geometric mean standard of 126 org/100 mL was exceeded.

Month	Sample Count	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	Number of Individual Sample Standard Exceedances (>1,260 org/100 mL)	Percent of Individual Sample Standard Exceedances (%)
June	5	86	19	580	0	0
July	5	226	45	866	0	0
August	5	80	34	110	0	0
September	1[a]	66	66	66	0	0

a. Not enough samples to assess compliance with the monthly geometric mean standard

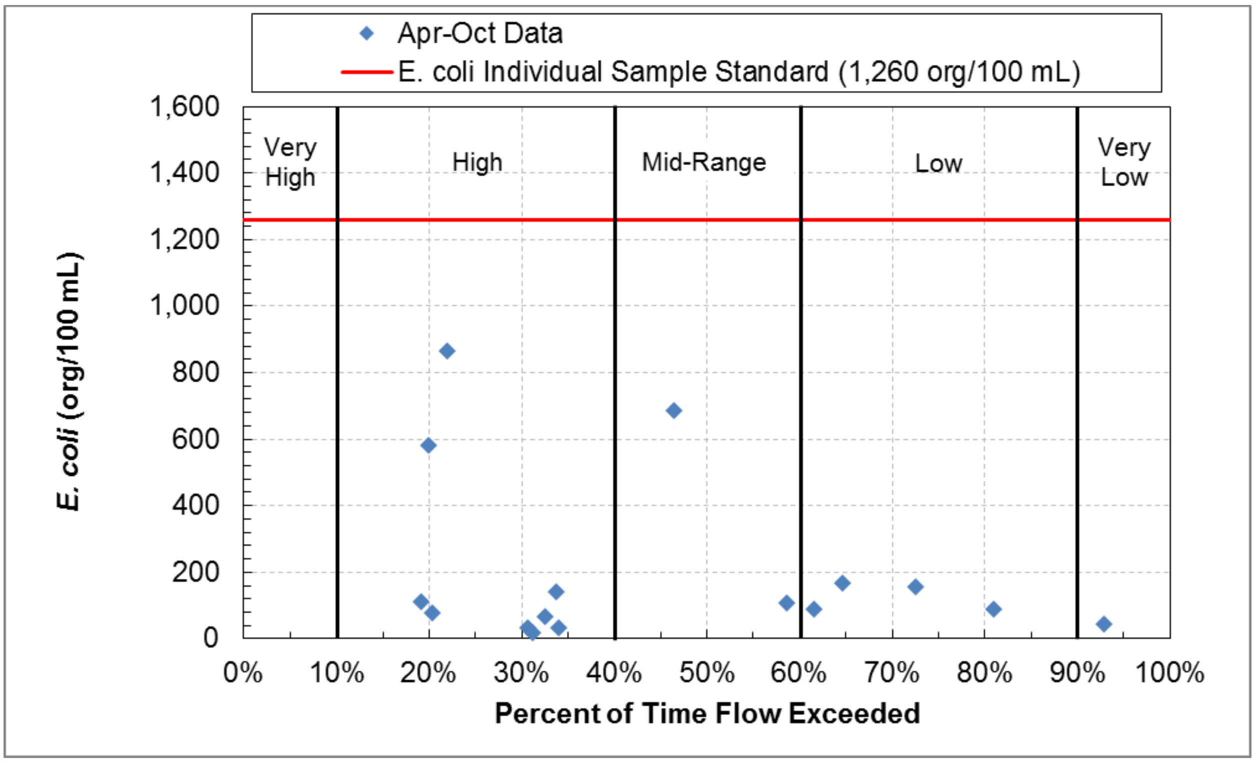


Figure 11. *E. coli* water quality duration plot, Stewart Creek.
(AUID 04010201-884), 2008–2010

3.3.6 Unnamed Creek (Merritt Creek; 04010201-987) *E. coli*

There are two monitoring stations on Unnamed Creek (Merritt Creek; Figure 5). The *E. coli* concentration exceeded the individual sample standard in one or more samples in four of the five years that were monitored (Table 17). Exceedances of the monthly geometric mean standard were observed in June through September (Table 18). Exceedances were observed under very high, high and low flow conditions. Most exceedances occurred under very high and high flow conditions (Figure 12).

Table 17. Annual Summary of *E. coli* data for Unnamed Creek (Merritt Creek).
(AUID 04010201-987, sites S004-975 and S008-483, Apr–Oct).

Year	Sample Count	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	Number of Individual Sample Standard Exceedances (>1,260 org/100 mL)	Percent of Individual Sample Standard Exceedances (%)
2008	6	186	30	980	0	0
2009	7	229	13	≥2,420[a]	2	29
2010	2	727	220	2,400	1	50
2015	20	334	13	2,400	7	35
2016	12	474	44	≥2,420[a]	4	33

a. 2,420 org/100mL is the method's maximum recordable value

Table 18. Monthly Summary of *E. coli* data for Unnamed Creek.
(Merritt Creek; AUID 04010201-987, sites S004-975 and S008-483; 2008–2010, 2015–2016). Values in red indicate months in which the monthly geometric mean standard of 126 org/100 mL was exceeded or the individual sample standard of 1,260 org/100 mL was exceeded in greater than 10% of the samples.

Month	Sample Count	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	Number of Individual Sample Standard Exceedances (>1,260 org/100 mL)	Percent of Individual Sample Standard Exceedances (%)
March	2	8	1	72	NA	NA
April	2[a]	21	19	23	0	0
May	3[a]	60	23	360	0	0
June	10	248	20	≥2,420[b]	4	40
July	12	413	26	≥2,420[b]	1	8
August	12	644	13	≥2,420[b]	6	50
September	6	858	166	2,400	3	50
October	2[a]	82	13	520	0	0

a. Not enough samples to assess compliance with the monthly geometric mean standard
b. 2,420 org/100mL is the method's maximum recordable value
NA: not applicable because the *E. coli* standard does not apply during this month

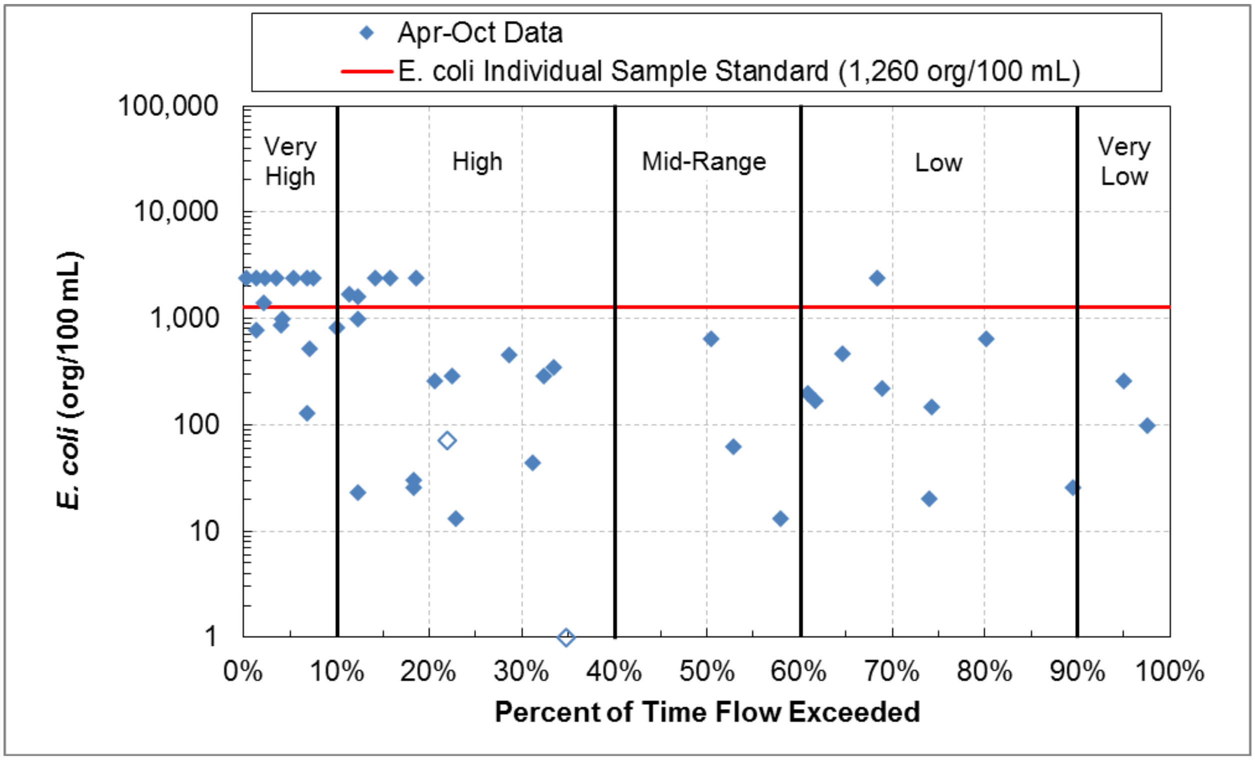


Figure 12. *E. coli* water quality duration plot, Unnamed Creek (Merritt Creek).
AUID 04010201-987), 2008–2010, 2015–2016. Hollow points indicate samples during months when the standard does not apply.

3.3.7 Tischer Creek (04010102-544) *E. coli*

There is one monitoring station located along the Tischer Creek impaired reach (Figure 5). The individual sample standard was exceeded in three of the six years monitored, with 10 exceedances in 2015 (Table 19). Exceedances of the monthly geometric mean standard were observed from April through September, and concentrations on average were highest in August and September (Table 20). *E. coli* concentrations were highest under very high and high flow conditions (Figure 13).

Table 19. Annual Summary of *E. coli* data for Tischer Creek.
(AUID 04010102-544, site S004-364, Apr–Oct)

Year	Sample Count	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	Number of Individual Sample Standard Exceedances (>1,260 org/100 mL)	Percent of Individual Sample Standard Exceedances (%)
2008	9	414	26	≥2,420[a]	2	22
2009	3	51	17	131	0	0
2011	6	324	160	690	0	0
2012	8	234	66	870	0	0
2015	20	1,051	86	2,400	10	50
2016	12	811	214	≥2,420[a]	5	42

a. 2,420 org/100mL is the method's maximum recordable value

Table 20. Monthly Summary of *E. coli* data for Tischer Creek.
(AUID 04010102-544, site S004-364; 2008–2009, 2011–2012, 2015–2016). Values in red indicate months in which the monthly geometric mean standard of 126 org/100 mL was exceeded or the individual sample standard of 1,260 org/100 mL was exceeded in greater than 10% of the samples.

Month	Sample Count	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	Number of Individual Sample Standard Exceedances (>1,260 org/100 mL)	Percent of Individual Sample Standard Exceedances (%)
March	3	228	66	690	NA	NA
April	5	131	17	980	0	0
May	5	150	26	870	0	0
June	11	506	66	≥2,420[b]	3	27
July	14	544	88	≥2,420[b]	4	29
August	13	871	160	≥2,420[b]	5	38
September	7	1,193	240	2,400	4	57
October	3[a]	838	250	2,400	1	33

a. Not enough samples to assess compliance with the monthly geometric mean standard

b. 2,420 org/100mL is the method's maximum recordable value

NA: not applicable because the *E. coli* standard does not apply during this month

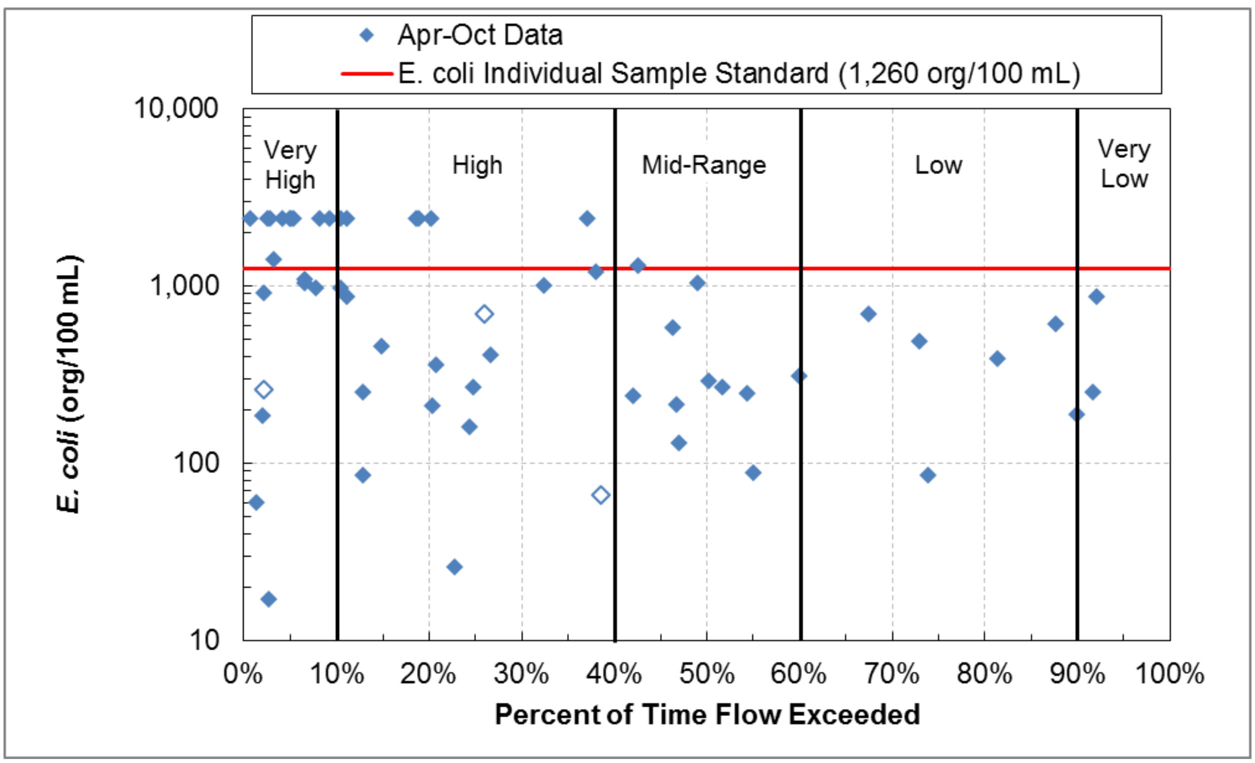


Figure 13. *E. coli* water quality duration plot, Tischer Creek.
(AUID 04010102-544), 2008–2009, 2011–2012, 2015–2016. Hollow points indicate samples during months when the standard does not apply.

3.3.8 Chester Creek (04010102-545) *E. coli*

There are two monitoring stations located along Chester Creek (Figure 5). Exceedances of the individual sample standard were observed in every year sampled, with the exception of 2009 (Table 21). The monthly geometric mean standard was exceeded from May through September, and concentrations on average were highest in August (Table 22). Individual sample standard exceedances occurred under all flow conditions (Figure 14).

Table 21. Annual Summary of *E. coli* data for Chester Creek.
(AUID 04010102-545, sites S004-953 and S008-481, Apr–Oct).

Year	Sample Count	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	Number of Individual Sample Standard Exceedances (>1,260 org/100 mL)	Percent of Individual Sample Standard Exceedances (%)
2008	9	1,318	365	≥2,420[a]	6	67
2009	3	20	5	79	0	0
2011	6	917	270	2,400	3	50
2012	9	1,376	260	2,400	7	78
2015	20	493	20	2,400	8	40
2016	12	380	38	≥2,420[a]	3	25

a. 2,420 org/100mL is the method's maximum recordable value

Table 22. Monthly Summary of *E. coli* data for Chester Creek.
(AUID 04010102-545, sites S004-953 and S008-481; 2008–2009, 2011–2012, 2015–2016). Values in red indicate months in which the monthly geometric mean standard of 126 org/100 mL was exceeded or the individual sample standard of 1,260 org/100 mL was exceeded in greater than 10% of the samples.

Month	Sample Count	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	Number of Individual Sample Standard Exceedances (>1,260 org/100 mL)	Percent of Individual Sample Standard Exceedances (%)
March	3	42	6	153	NA	NA
April	5	38	5	1,300	1	20
May	5	225	42	921	0	0
June	12	483	79	≥2,420[b]	3	25
July	14	813	38	2,400	7	50
August	13	1,494	201	≥2,420[b]	10	77
September	7	907	89	≥2,420[b]	5	71
October	3[a]	557	130	≥2,420[b]	1	33

a. Not enough samples to assess compliance with the monthly geometric mean standard

b. 2,420 org/100mL is the method's maximum recordable value

NA: not applicable because the *E. coli* standard does not apply during this month

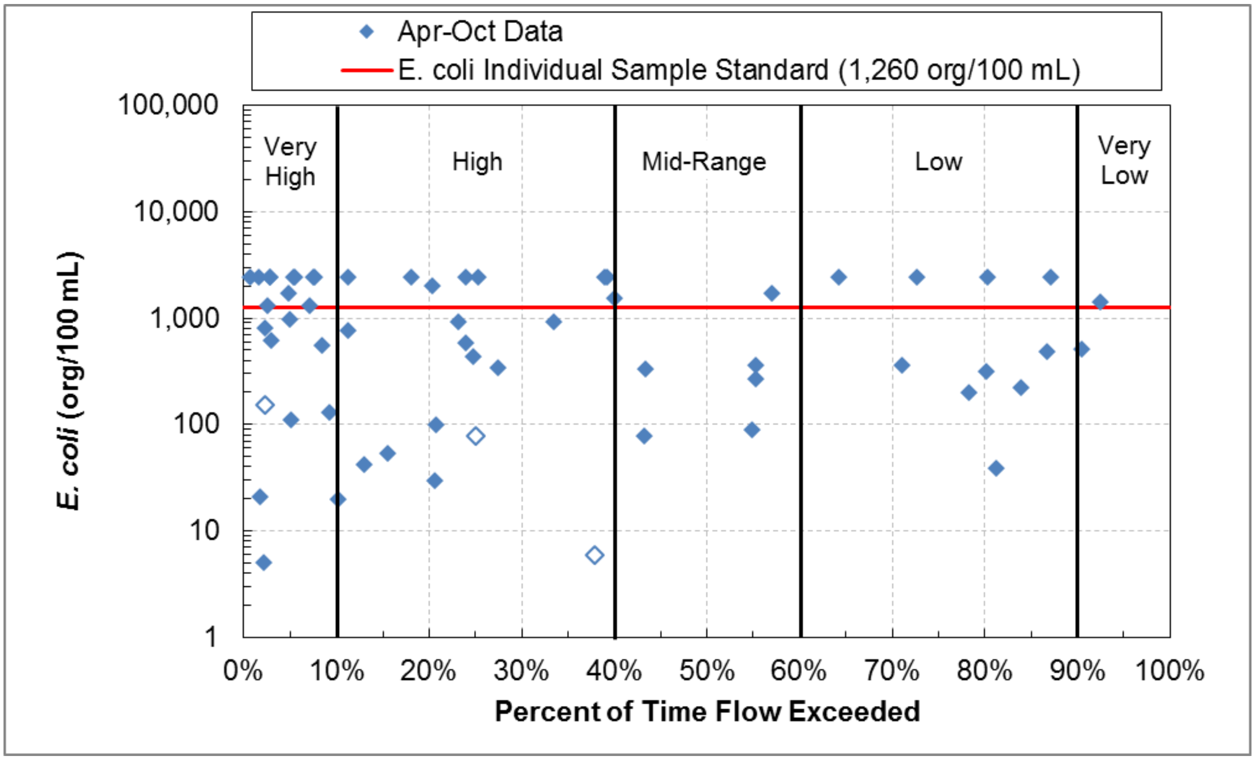


Figure 14. *E. coli* water quality duration plot, Chester Creek.
(AUID 04010102-545), 2008–2009, 2010–2011, 2015–2016. Hollow points indicate samples during months when the standard does not apply.

3.3.9 Amity Creek (04010102-511) Total Suspended Solids

There are two monitoring stations on the impaired reach of Amity Creek (Figure 6). Average annual TSS concentrations in Amity Creek ranged from 12 to 124 mg/L (Table 23). Greater than 10% of samples exceeded the 10 mg/L TSS standard in each year that was monitored. Monthly means (during the months in which the standard applies) varied from 21 to 105 mg/L, with the highest concentrations on average in September (Table 24). The standard was exceeded during mid-range to very high flows, with higher concentrations occurring under very high flows (Figure 15). No samples were collected under very low flow conditions.

Table 23. Annual Summary of TSS data for Amity Creek.
(AUID 04010102-511, sites S001-757 and S005-485, Apr–Sep). Values in red indicate years in which the numeric criteria of 10 mg/L was exceeded in greater than 10% of the samples.

Year	Sample Count	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Number of Exceedances	Frequency of Exceedances
2007	10	36	0.5	280	3	30%
2008	39	32	0.5	247	23	59%
2009	8	124	2	661	5	63%
2010	19	38	3	182	17	89%
2015	18	124	4	1,068	14	78%
2016	15	35	4	139	12	80%

Table 24. Monthly Summary of TSS data for Amity Creek.

(AUID 04010102-511, sites S001-757 and S005-485; 2007–2010, 2015–2016). Values in red indicate months in which the numeric criteria of 10 mg/L was exceeded in greater than 10% of the samples.

Month	Sample Count	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Number of Exceedances	Frequency of Exceedances
March	19	45	3	324	NA	NA
April	33	21	3	68	21	64%
May	12	41	1	182	8	67%
June	22	74	3	314	16	73%
July	12	26	2	172	6	50%
August	15	84	0.5	661	12	80%
September	15	112	7	1068	11	73%
October	10	66	3	246	NA	NA

NA: not applicable because the TSS standard does not apply during this month

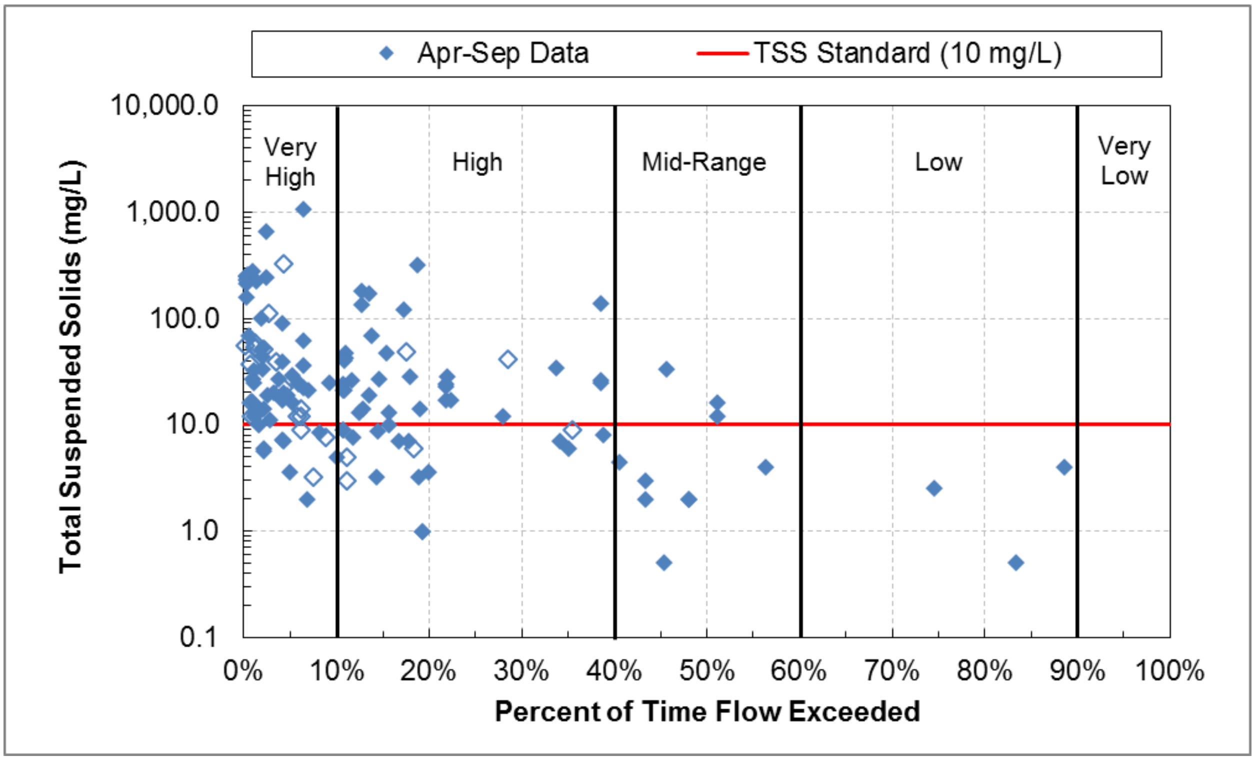


Figure 15. TSS water quality duration plot, Amity Creek.

(AUID 04010102-511), 2006–2010, 2015–2016. Hollow points indicate samples during months when the standard does not apply. Samples collected outside the standard window on March 8th, 9th and 16th 2016 could not be plotted due to ice and no recorded flow value at Amity Creek at Duluth, Occidental Blvd. Samples ranged from 9 to 18 mg/L.

3.3.10 Amity Creek, East Branch (04010102-540) Total Suspended Solids

There are two monitoring stations located along the impaired reach of East Branch Amity Creek (Figure 6). Annual mean TSS ranged from 7 to 33 mg/L, and the TSS standard of 10 mg/L was exceeded in greater than 10% of samples during all monitoring years (Table 25). Monthly means (during the months in which the standard applies) varied from 2 to 68 mg/L, and concentrations on average were highest in May and October (Table 26). TSS concentrations were highest under very high and high flow conditions (Figure 16).

Table 25. Annual Summary of TSS data for Amity Creek, East Branch.

(AUID 04010102-540, sites S004-950 and S005-488, Apr–Sep). Values in red indicate years in which the numeric criteria of 10 mg/L was exceeded in greater than 10% of the samples.

Year	Sample Count	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Number of Exceedances	Frequency of Exceedances
2008	10	23	1	154	3	30%
2009	7	7	0.6	30	1	14%
2010	20	18	3	82	10	50%
2012	11	21	0.4	71	4	36%
2013	12	33	3	216	6	50%

Table 26. Monthly Summary of TSS data for Amity Creek, East Branch.

(AUID 04010102-540, sites S004-950 and S005-488; 2008–2010, 2012–2013). Values in red indicate months in which the numeric criteria of 10 mg/L was exceeded in greater than 10% of the samples.

Month	Sample Count	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Number of Exceedances	Frequency of Exceedances
March	8	26	4	59	NA	NA
April	10	15	0.6	53	3	30%
May	14	47	1	216	9	64%
June	12	28	2	154	6	50%
July	8	2	1	4	0	0%
August	9	7	0.6	16	4	44%
September	7	8	0.4	16	2	29%
October	7	68	2	209	NA	NA

NA: not applicable because the TSS standard does not apply during this month

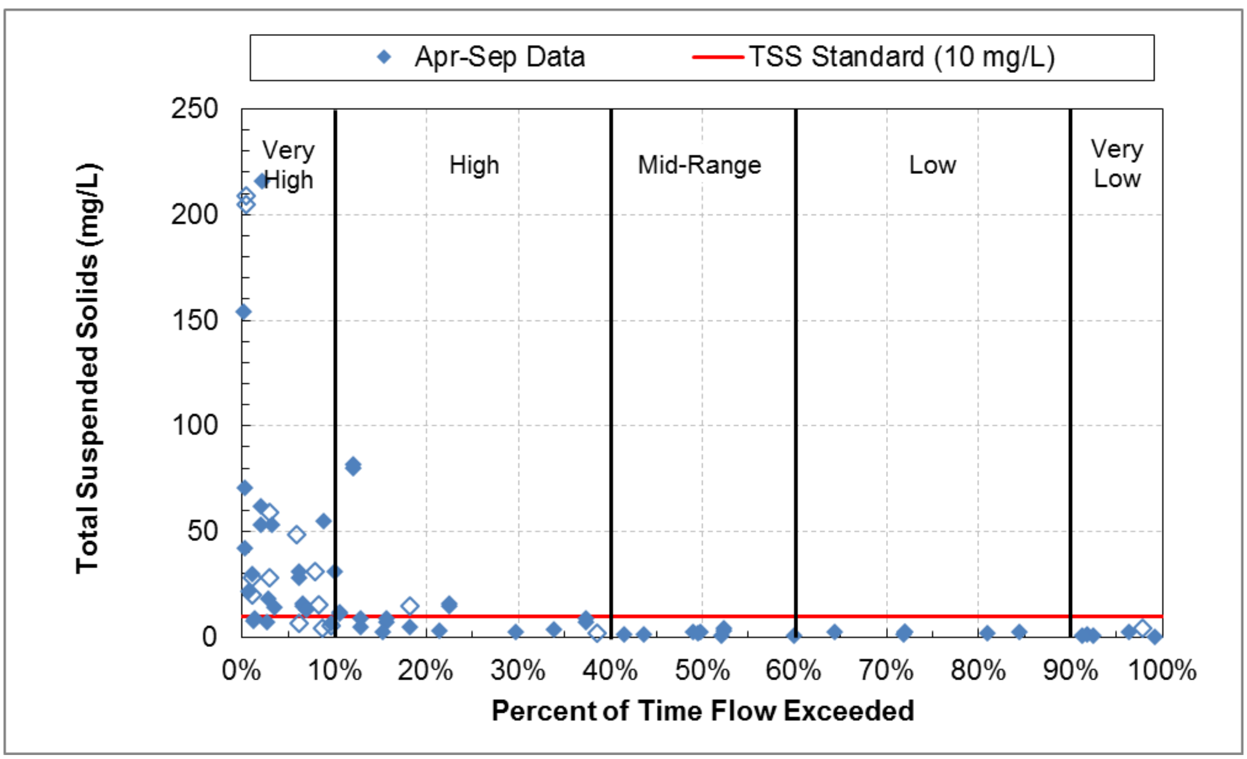


Figure 16. TSS water quality duration plot, Amity Creek, East Branch.

(AUID 04010102-540), 2008–2010, 2012–2013. Hollow points indicate samples during months when the standard does not apply.

3.3.11 Lester River (04010102-549) Total Suspended Solids

There are 14 monitoring stations located along Lester River (Figure 6). Annual mean TSS concentrations ranged from 1 to 51 mg/L, with a marked increase in annual means during 2014 through 2016 (Table 27). Greater than 10% of samples exceeded the 10 mg/L TSS standard in four of the six monitored years. During the months in which the standard applies, monthly means ranged from 5 to 57 mg/L. Concentrations on average were highest in March (Table 28). TSS concentration increased with flow, with the highest concentrations under very high and high flow conditions (Figure 17).

Table 27. Annual Summary of TSS data for Lester River.

(AUID 04010102-549, sites S000-258, S001-329, S003-389, S006-238, S006-281, S007-811, S007-812, S007-814, S007-815, S007-816, S007-817, S007-818, S007-819 and S008-837, Apr–Sep). Values in red indicate years in which the numeric criteria of 10 mg/L was exceeded in greater than 10% of the samples.

Year	Sample Count	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Number of Exceedances	Frequency of Exceedances
2008	6	4	0.5	12	1	17%
2010	7	2	0.5	3	0	0%
2011	10	1	0.2	2	0	0%
2014	71	36	0.5	400	33	46%
2015	77	51	0.5	430	40	52%
2016	35	23	0.5	220	12	34%

Table 28. Monthly Summary of TSS data for Lester River.

(AUID 04010102-549, sites S000-258, S001-329, S003-389, S006-238, S006-281, S007-811, S007-812, S007-814, S007-815, S007-816, S007-817, S007-818, S007-819 and S008-837; 2007–2008, 2010–2011, 2014–2016). Values in red indicate months in which the numeric criteria of 10 mg/L was exceeded in greater than 10% of the samples.

Month	Sample Count	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Number of Exceedances	Frequency of Exceedances
January	1	2	2	2	NA	NA
February	1	5	5	5	NA	NA
March	27	146	0.5	1,800 [a]	NA	NA
April	51	55	0.5	400	31	61%
May	26	24	0.2	140	10	38%
June	34	28	0.5	340	14	41%
July	23	12	0.5	86	6	26%
August	29	5	0.5	27	4	14%
September	43	57	0.5	430	21	49%
October	20	2	1	9	NA	NA
November	6	30	0.5	140	NA	NA

a. Sample exceeded the laboratory acceptance limit and required dilution due to high concentration.

NA: not applicable because the TSS standard does not apply during this month

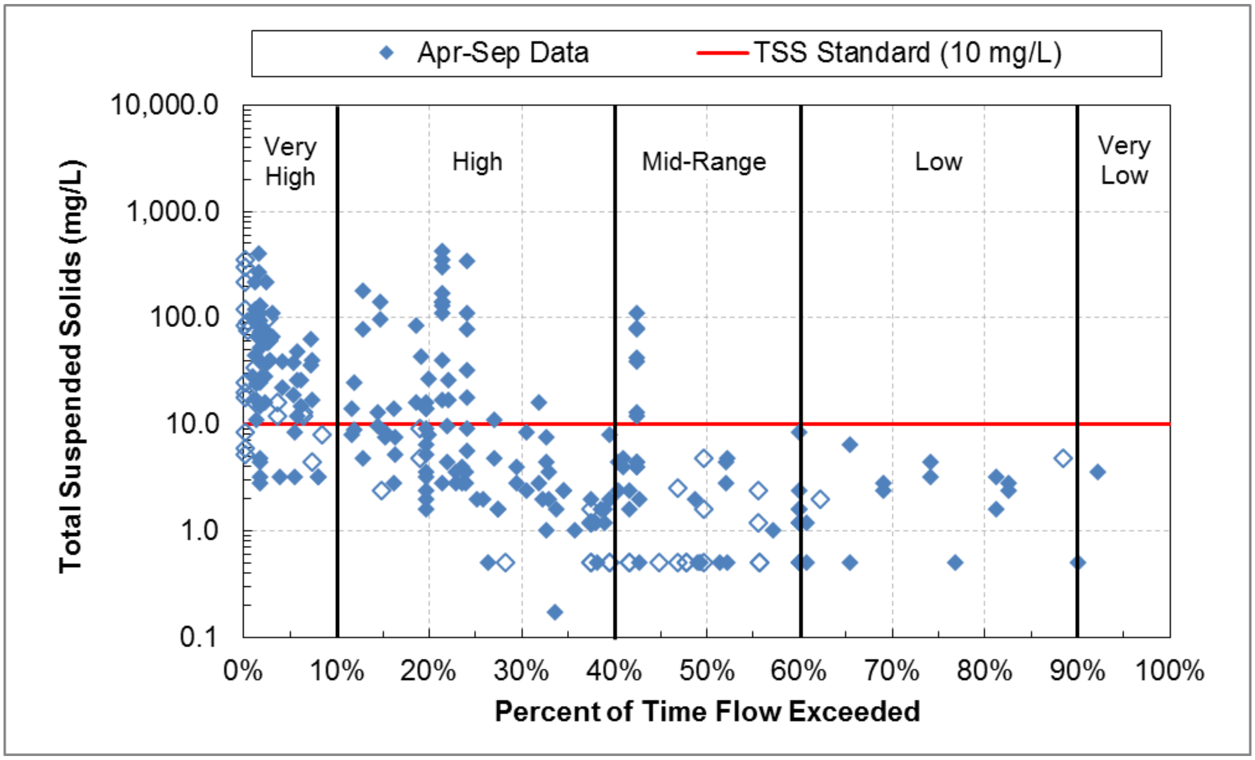


Figure 17. TSS water quality duration plot, Lester River.
(AUID 04010102-549), 2007–2008, 2010–2011, 2014–2016. Hollow points indicate samples during months when the standard does not apply. Several samples outside the standard window, two samples from November 2015, and four samples from March 2016, are not plotted due to no recorded flow value at Lester River near Duluth, CSAH10. Samples range from 33 to 1,800 mg/L.

3.4 Sediment Pollutant Source Summary

Sediment loading in the Duluth Urban Area Subwatershed is the result of both watershed and near-channel sources. Erosional processes occurring on the landscape are a result of land use changes that have increased the amount of sediment available for movement and altered the natural hydrology to increase peak flows and runoff volumes. Near-channel sources include bluff and bank erosion and channel scour, and are a result of historic and current land alterations as well as natural processes.

The source assessment evaluated permitted sources, specifically regulated stormwater, and nonpermitted sources from the watershed and near-channel areas. Potential sources were identified through the MPCA permit information and monitoring records, county and municipal records, watershed modeling studies, watershed and stream-specific studies and data, and field data.

3.4.1 Permitted Sources

Permitted sources are those sources that are regulated by a National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) permit and include wastewater (municipal and industrial), stormwater, and confined animal feeding operations (CAFOs). In the Duluth Urban Area, permitted sources include stormwater from municipal separate storm sewer systems (MS4s), industrial stormwater, and construction stormwater. There are no regulated CAFOs or municipal wastewater sources in the watershed. Regional wastewater treatment is provided by the Western Lake Superior Sanitary District, which discharges to the St. Louis Bay.

Municipal Separate Storm Sewer Systems

MS4s are defined as the conveyance systems owned or operated by an entity such as a state, city, township, county, district, or other public body having jurisdiction over management of stormwater. The conveyance system includes ditches, roads, storm sewers, stormwater ponds, etc. The MS4 stormwater permit holds regulated permittees responsible for stormwater discharging from the conveyance system they own and/or operate.

There are nine regulated MS4s in the Duluth Urban Area including:

- Duluth
- Hermantown
- Midway Township
- Proctor
- Rice Lake
- University of Minnesota Duluth (UMD)
- Lake Superior College
- St. Louis County (roads)
- Minnesota Department of Transportation (MnDOT) Outstate District (roads)

Appendix C includes detailed maps of MS4 areas. Stormwater runoff from regulated MS4s was estimated together with watershed runoff from nonpermitted areas, discussed under nonpermitted sources. The maps are valuable information graphics and are referenced throughout the document. The appendix location provides quick access to information.

Industrial Stormwater

Industrial stormwater is regulated through an NPDES/SDS permit when stormwater discharges have the potential to come into contact with materials and activities associated with industrial activities. Loading from industrial stormwater is inherently incorporated in the watershed runoff estimates, discussed under nonpermitted sources.

Wisconsin Central Ltd (MN0000361), which is a subsidiary of Canadian National Railroad, is permitted to discharge industrial stormwater in the Kingsbury Creek Watershed. This railroad facility discharges to Kingsbury Creek through five separate storm sewer outlets (SD 001–SD 005). Five stormwater discharge outfalls channel water from this facility to Kingsbury Creek. Two of the discharges are controlled by Stormceptor sediment control devices, one is controlled by a stormwater pond, and the other two are direct culvert discharges. Discharge Monitoring Reports (DMR) from 2012 through 2016 were investigated to determine compliance with the permitted limit for TSS of 30 mg/L. Nineteen exceedances of the permit limit were observed from 2012 through 2016. Observed values for TSS at monitored outfalls ranged from 0.5 mg/L to 136 mg/L, with an average value of 15 mg/L.

There are two industrial stormwater sites permitted through the general industrial permit in TSS-impaired watersheds: Equipment Rental Co (MNR053D22) and Hartel's/DBJ Disposal Companies (MNRNE38MW).

Construction Stormwater

Construction stormwater is an additional source of sediment in the Duluth Urban Area Subwatershed regulated through an NPDES/SDS permit. Untreated stormwater that runs off a construction site often carries sediment and other pollutants to surface water bodies. An NPDES/SDS permit is needed for construction activity that disturbs one acre or more of soil, or if the activity is part of a larger development. A NPDES/SDS permit may also be ordered if the MPCA determines that the activity poses a risk to water resources. Coverage under the construction stormwater general permit requires sediment and erosion control measures that reduce stormwater pollution during and after construction activities. On average, approximately 0.01% of the watershed area is permitted under the construction stormwater permit in any given year (St. Louis County average of 2010 through 2015; Minnesota Stormwater Manual contributors 2017). Local regulations may require additional permits for land disturbance activities for sites smaller than one acre (e.g., City of Duluth).

3.4.2 Nonpermitted Sources

Nonpermitted sediment inputs in the Duluth Urban Area Subwatershed can be dominated by watershed (upland) loading or near-channel sources, depending on the impaired segment and flow conditions. A summary of these sources is provided below, as well as spatial analysis of sampling data.

Upland sediment loading rates, or yields, vary widely from place to place and are influenced by local conditions such as soil erodibility, slope, and precipitation patterns. Land use also has a strong influence on sediment yield, and most studies show the lowest rates from forest and other uses with good vegetation cover, somewhat higher rates for relatively unmanaged grasslands, and high rates for developed land and agricultural production. Loading rates from urban land are typically higher due to the effects of flow concentration from impervious surfaces, higher runoff volumes, and erosion hotspots in ditches and ephemeral headwater channels receiving flow from storm drains.

Table 29 and Figure 18 present the average annual sediment yields for each land use in the TMDL watersheds (Tetra Tech 2019; see Appendix A). The yields compare reasonably well with reference ranges and the assumed land use progression of low to high sediment yields. Variation in rates between watersheds is due to a variety of factors, including differences in soil erodibility, slope, and precipitation.

Sediment loading rates aggregated to the model subbasin scale are shown in Figure 19 and Figure 20. Higher loading rates tend to be associated with developed land and impervious surfaces.

Table 29. Annual average upland sediment yields by land use in sediment-impaired waters (1995-2016).

Land Use	Average Sediment Yield (lbs/acre/year)			
	Amity	E Br Amity	Kingsbury	Lester
Residential (35% Impervious)	207.1	223.9	186.7	197.2
Low Intensity (43% Impervious)	230.1	234.7	200.9	215.6
High Intensity (64% Impervious)	260.8	265.7	236.8	230.3
Road (36% Impervious)	276.5	310.7	252.3	271.2
Outcrop	58.4	61.1	57.0	59.7
Deciduous Forest	34.8	37.6	27.1	31.3
Evergreen Forest	27.6	31.9	21.7	22.6
Forest Wetlands	6.4	6.3	4.8	4.3
Herbaceous Wetlands	7.5	7.6	5.6	5.7
Open Water	0.0	0.0	0.0	0.0
Grassland/Shrubland	61.7	66.0	49.4	56.9
Pasture/Hay	179.2	190.7	151.0	177.4

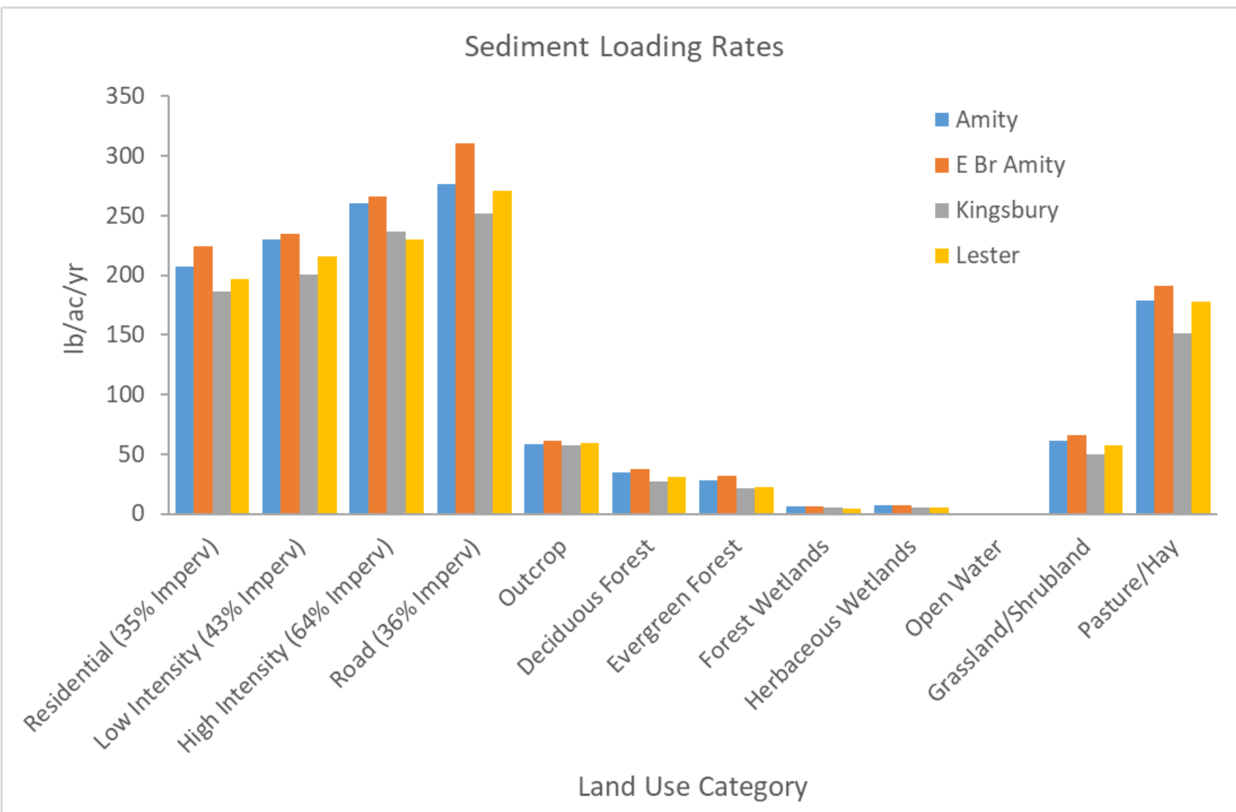


Figure 18. Annual average upland sediment yields in sediment-impaired waters (1995-2016).

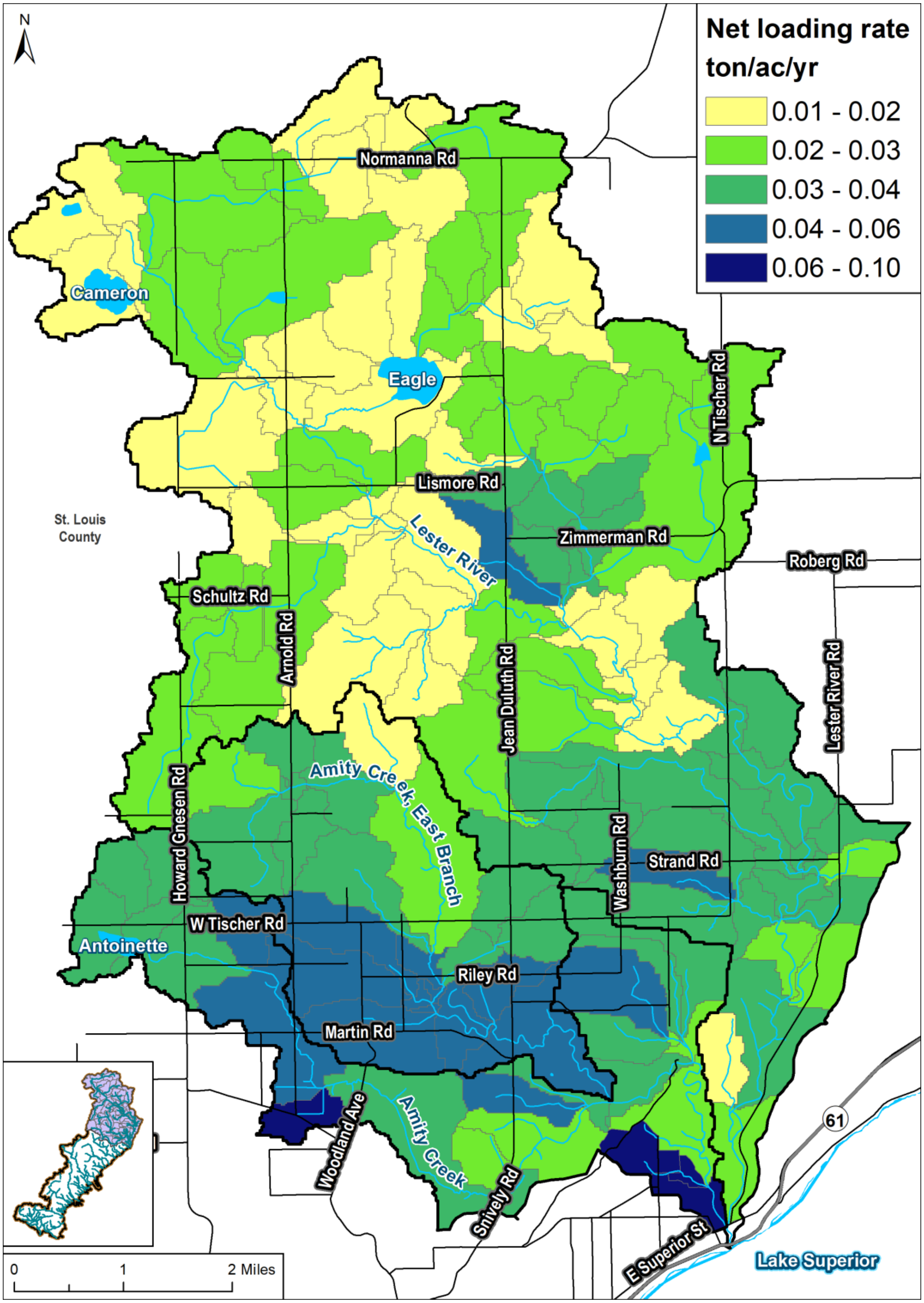


Figure 19. Annual average sediment loading rates in Lester River, Amity Creek, and East Branch Amity Creek watersheds (1995-2016; Tetra Tech 2019).

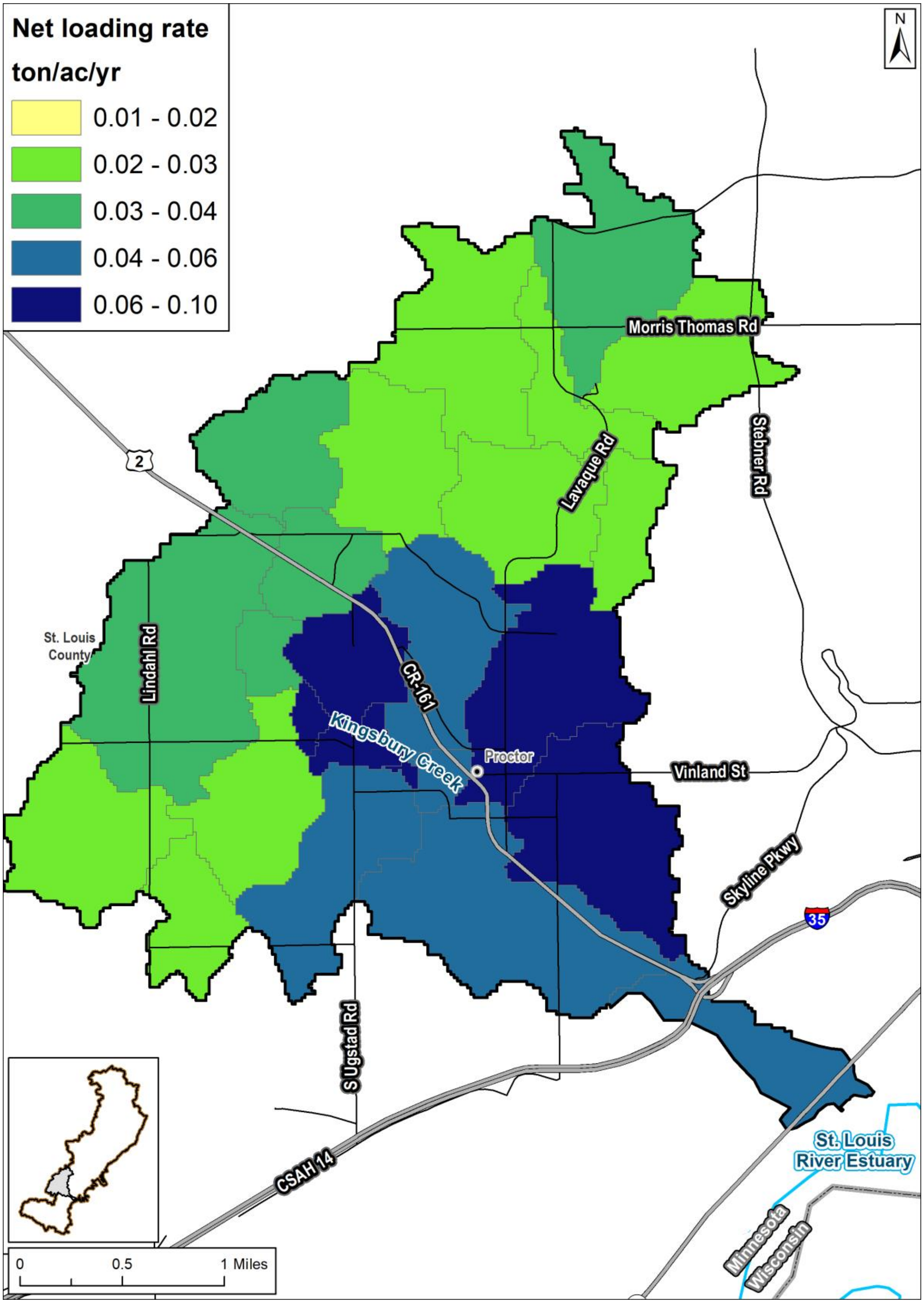


Figure 20. Annual average sediment loading rates in Kingsbury Creek Watershed (1995-2016; Tetra Tech 2019).

Near-channel sources include bluff and bank erosion and channel scour. Bluff and bank erosion is a significant source of sediment loading throughout the North Shore (Wick 2013, Nietzel 2014). Bluffs, however, are likely only a major source to the Duluth Urban Area Subwatershed during high flow events, such as spring snow melt and major precipitation events.

Near-channel sources that are contributing to impairments in the watershed are the result of historic and current land alterations. These activities (e.g., clearing of forests, roads, development) have changed the hydrology of the watershed resulting in increased snowmelt and runoff rates, and increased peak flows and volumes. This change in hydrology sets in motion the channel evolution process which results in the river changing its form to accommodate this change in hydrology. Near-channel erosion is, in part, due to this process.

Loadings from bluffs along the Lester River, Amity Creek, and Tischer Creek in the watershed models are specified based on high risk erosion areas identified as part of a LiDAR-based bluff assessment conducted by the Natural Resources Research Institute (NRRI; 2015). Bluff erosion along Mission Creek is also identified as a significant source (Fitzpatrick et al. 2016; Manopkawee 2015; Gran et al. 2016). In addition, the extent of clay till soils and locations of high slope areas were identified in 2016 by the DNR to focus land management efforts.

Sources of sediment in Amity Creek[1], East Branch Amity Creek, Lester River, and Kingsbury Creek during days with TSS water quality standard exceedances occurring between April and September are summarized based on HSPF model outputs in Figure 21. These charts answer the question “What is causing or contributing to exceedances of the water quality standard?” For all of the streams, developed land covers and near-channel sources are contributing the majority of the load. Table 30 summarizes the source information and also provides the percent of the watershed area attributed to the source. A comparison of upland areas versus relative load contribution indicates that while undeveloped land occupies the majority of the area in each of the watersheds, the combined load from all undeveloped land is less than the load from the developed land.

[1] The assessment of Amity Creek includes its entire watershed, including East Branch Amity Creek.

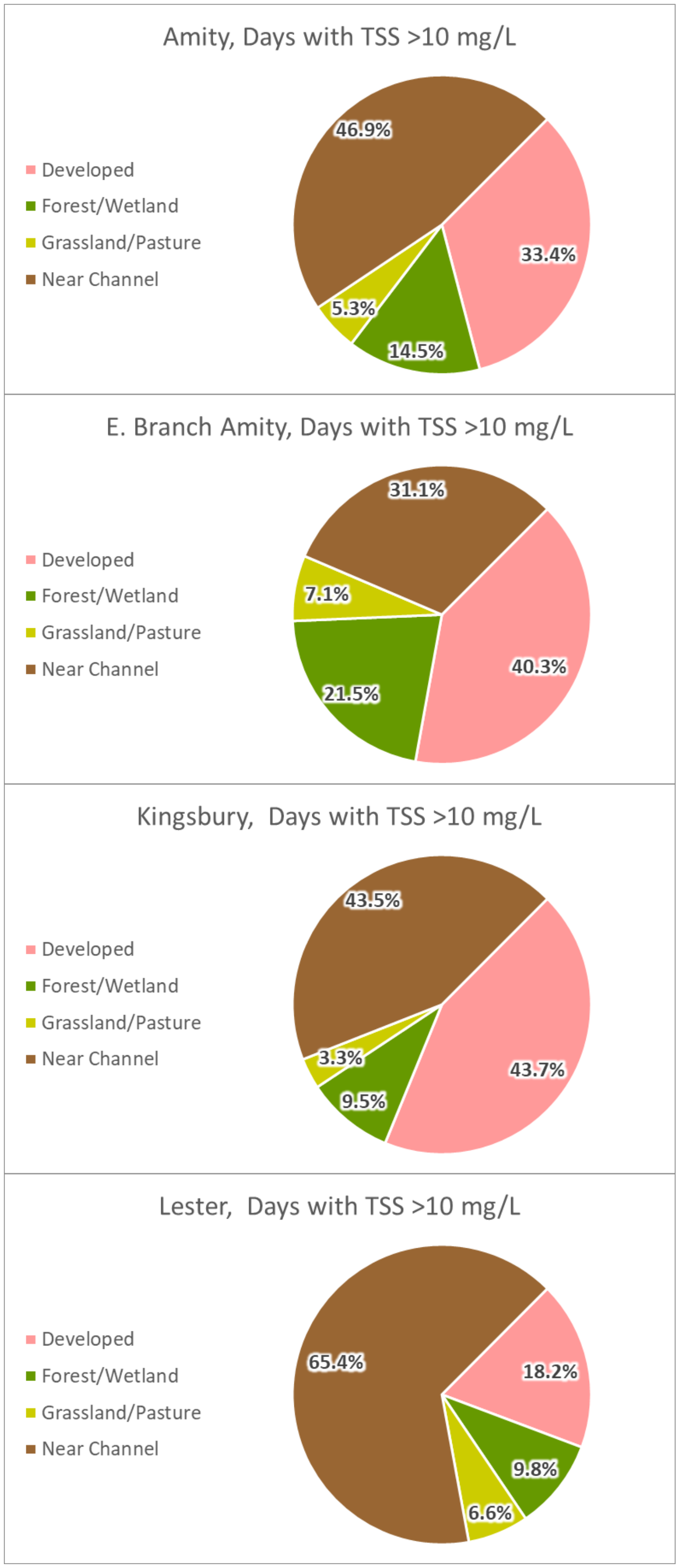


Figure 21. Sediment source apportionment for days with water quality standard exceedances (i.e., >10 mg/L).

Table 30. Sediment source apportionment for days with water quality standard exceedances, compared with percent of watershed area.

Watershed	Developed		Near-channel		Grassland/Pasture		Forest/Wetland	
	% area	% load	% area	% load	% area	% load	% area	% load
Amity Creek	28	33.4	--	46.9	13	5.3	60	14.5
East Branch Amity Creek	24	40.3	--	31.1	12	7.1	64	21.5
Lester River	20	18.2	--	65.4	15	6.6	66	9.8
Kingsbury Creek	36	43.7	--	43.5	9	3.3	55	9.5

Near-channel loads contribute relatively little load to exceedances at lower flows, but become increasingly important at higher flows. Figure 22 provides an example showing cumulative sediment loads for flow percentiles on days with exceedances for Amity Creek. The near-channel load contribution is minimal at lower flows, but becomes more significant around the 60th flow percentile. Results are similar for the other watersheds, though the thresholds differ (75th flow percentile for East Branch Amity, 80th flow percentile for Kingsbury, and the 10th flow percentile for Lester). The importance of near-channel loads is greater for lower flows in the Lester River due to the presence of significant bluff collapse inputs as documented in existing studies.

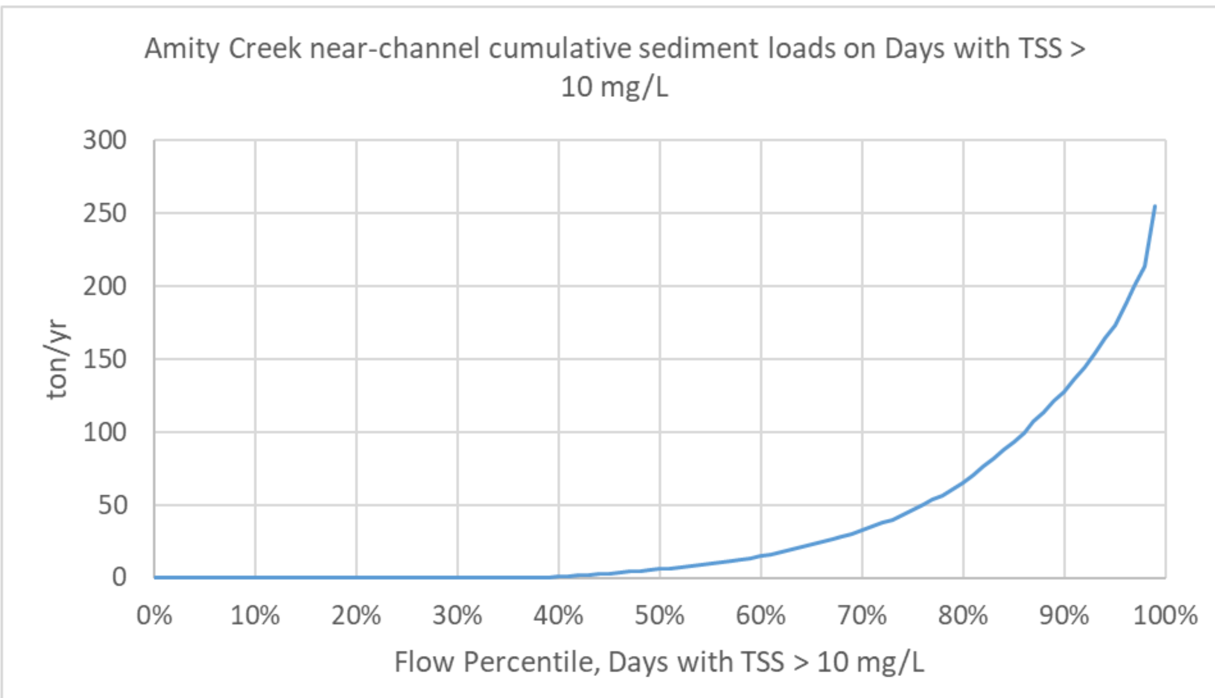


Figure 22. Near-channel sediment loads on days with TSS water quality standard exceedances by flow percentile for Amity Creek.

Stream-specific assessments

Stream-specific assessments have also been conducted for TSS-impaired streams, and the results of this work were incorporated into the HSPF models, described above. As part of the stressor identification process (MPCA 2016, Jennings et al. 2017), Bank Assessment for Nonpoint source Consequences of

Sediment (BANCS) modeling was conducted. The BANCS model was developed by Dave Rosgen in 1996 and adopted by the EPA in 2006 as part of the Watershed Assessment of River Stability and Sediment Supply, or WARSSS framework. The BANCS model combines Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) measurements to estimate an erosion rate. Measurements are completed at an individual bank scale and extrapolated to a reach scale. At each assessment bank, characteristics such as plant root depth and density, bank height, and bank angle were used to calculate a BEHI score, and the location of dominant channel flow relative to the bank or depositional properties and other channel characteristics were used to calculate an NBS score. BEHI and NBS relationship curves developed for the BANCS model were then used to predict a bank recession rate. Length and height of the bank are multiplied by the predicted annual recession rate to estimate a mean annual sediment loading rate (for both bedload and suspended sediment) for each bank.

Amity Creek, Amity Creek East Branch, and Lester River

With the majority of the Lester River and Amity Creek East Branch subwatersheds made up of forest and wetland, developed land uses in the Amity Creek Subwatershed are likely potential watershed sources of sediment for both streams. Amity Creek contains 29 total stream crossings or an average of 1.1 stream crossings per stream mile, all of which are potential sources of sediment (SSLSWCD 2017). Figure 23 includes the location of clay lacustrine soils and identified high erosion risk bluffs (NRRI 2015).

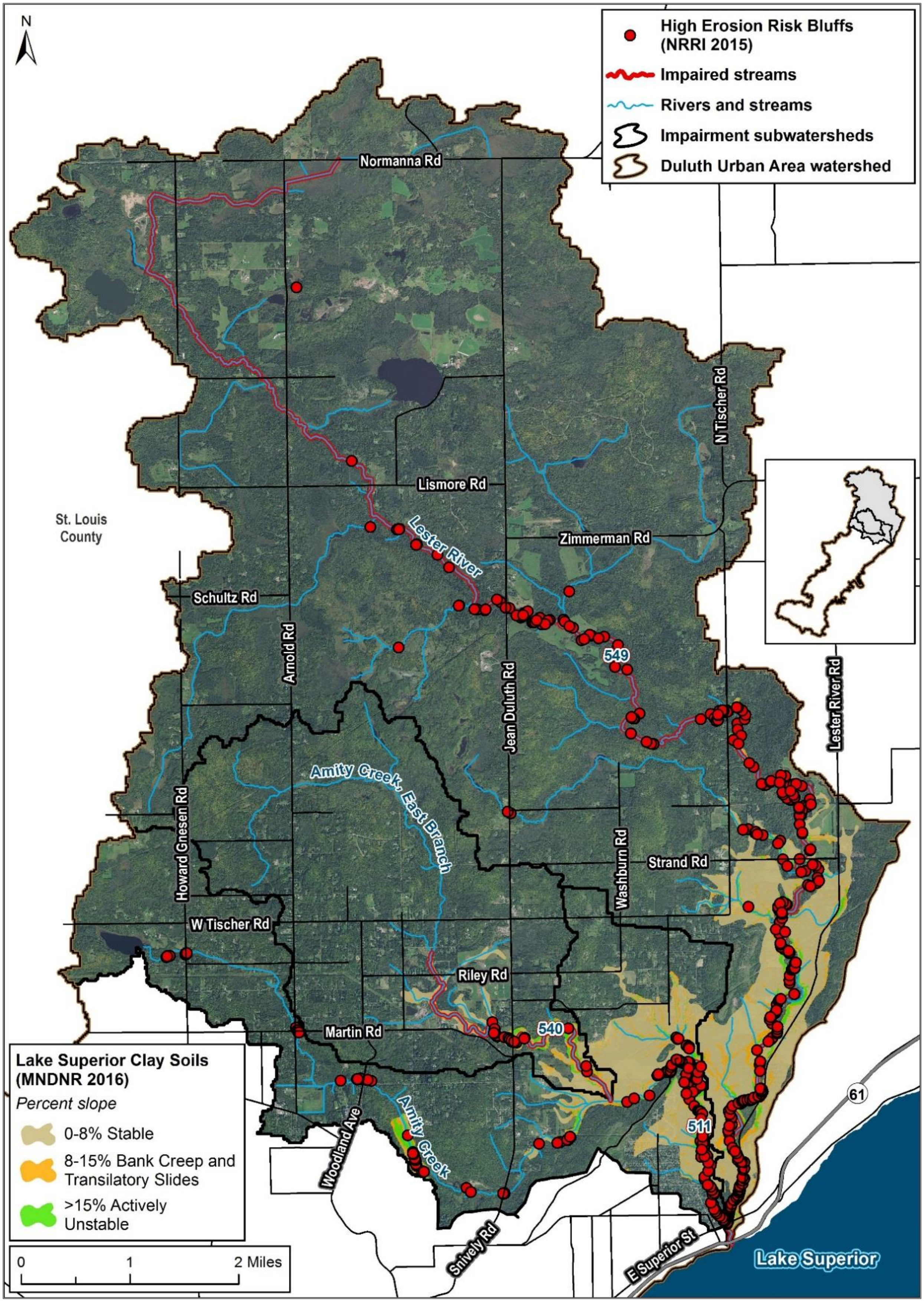


Figure 23. Potential sediment source areas identified in the Lester River and Amity Creek subwatersheds.

In addition to watershed loading, stream channel instability and bank erosion are causes of water quality impairment on the three reaches (Figure 24). A stressor identification study for Amity Creek and East Branch Amity Creek was completed in 2017 (Jennings et al. 2017; see Appendix B) to evaluate sources of sediment and identify priority areas for restoration (Figure 24). Stream reaches were classified for level of concern based primarily on geomorphic stability as evidenced by bank erosion and channel evolution.

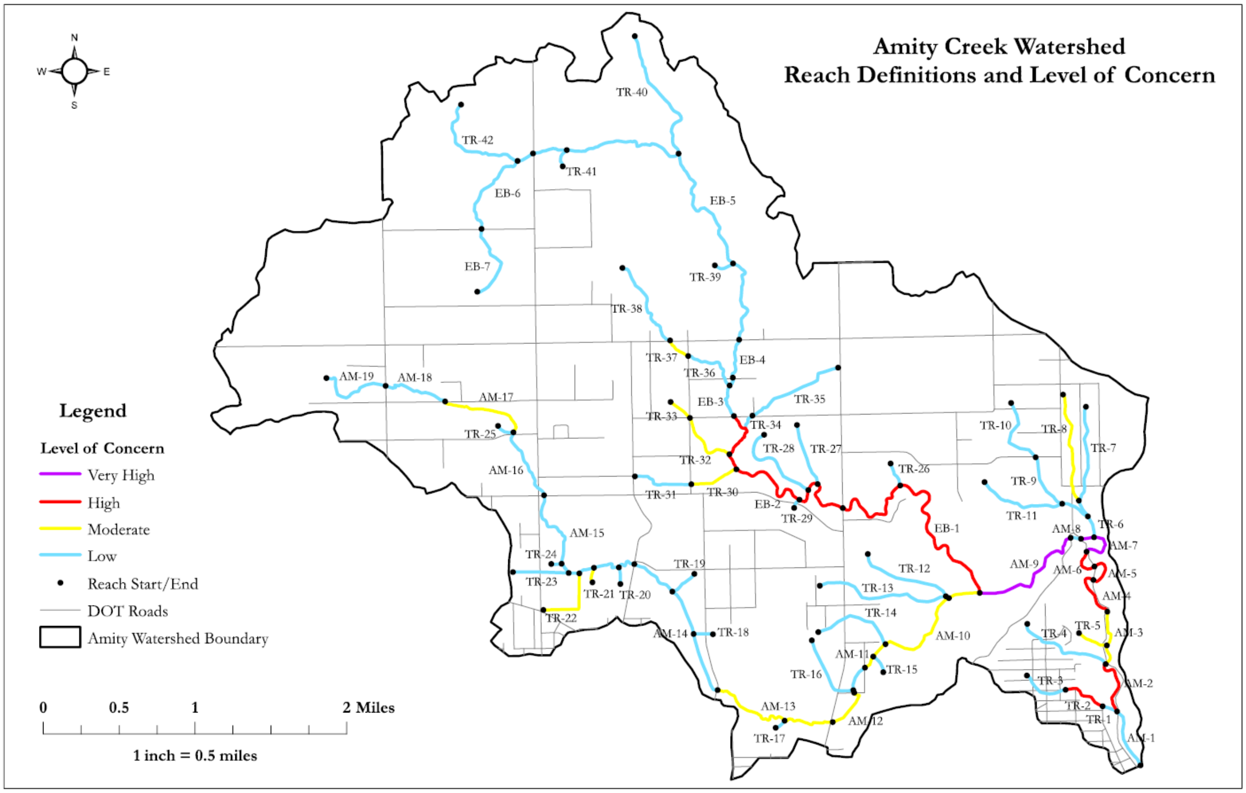


Figure 24. Amity Creek Subwatershed reaches with identified level of concern (from Jennings et al. 2017).

BANCS modeling conducted as part of the stressor identification study found that streambank erosion contributed 5,647 tons of sediment per year to the East Branch Amity Creek, and that the following two reaches contribute over 90% of the total loading from stream bank erosion to the stream:

Reach EB-1 (East Branch Amity Creek between Jean Duluth Rd and main stem confluence)

- Horizontal instability and migration throughout the reach
- High levels of bank erosion and departure from stable conditions
- Poor habitat and vegetation in spots

Reach EB-2 (East Branch Amity Creek between Riley Road and Jean Duluth Road)

- Horizontal instability and migration throughout the reach
- Very high terraces that the stream cuts into and causes large amounts of sediment to be added to the creek
- Tree created blockages that have caused high near bank shear stresses and movement in the channel

Similar results were seen in Amity Creek. The geomorphic assessment for Amity and East Branch Amity found that streambank erosion contributed 9,170 tons of sediment per year to Amity Creek, with the following two reaches contributing almost two thirds of the total load:

Reach AM-7 (main stem of Amity Creek between Bridges #6 and #7 on Seven Bridges Road)

- Very large terraces and hillslope failure contribute large amounts of sediment to the system
- Vertical instability and horizontal movement throughout the reach, extreme in some locations
- Limited flood plain creates high stress from streamflow on banks

Reach AM-9 (main stem Amity Creek between the East Branch confluence and Hawk Ridge Road)

- Vertical instability and horizontal movement throughout the reach, extreme in some locations
- Instability and sediment transport problems caused by a beaver dam

These results suggest that near-channel sources of sediment in Amity Creek and East Branch Amity Creeks may be sufficiently addressed with targeted work on the four aforementioned stream segments. Concept plans for restoration projects on these four segments are provided in the stressor identification study (see Appendix B).

In addition to addressing near-channel sources, consideration should be given to upstream, watershed contributions that may be causing or contributing to the large bank instabilities listed above. Reductions in peak flows and runoff volumes, as well as changes in timing of runoff, may be needed to ensure the success of streambank stabilization projects.

Kingsbury Creek

The Kingsbury Creek Subwatershed has a fairly high level of development, at approximately 30%. Kingsbury Creek experiences short, highly elevated TSS loads during spring snowmelt, as well as precipitation events during the spring, summer, and fall months. Streambank and bluff erosion, unstable gully and ravine tributaries, and overland runoff from urban areas are all contributing excess sediment to this creek (MPCA 2016). Development in the watershed is likely contributing to erosive flows in the stream channel. Development that includes residential, commercial, and industrial areas, as well as connected roads, storm sewers, and ditches, can lead to increases in runoff volumes and peak flows being delivered to Kingsbury Creek. This altered hydrology contributes to near-channel sediment loading.

Manopkawee (2015) conducted a LiDAR-based analysis to identify erosional hotspots in many Duluth area streams. Figure 25 identifies the location of clay lacustrine soils and erosional hotspots in Kingsbury Creek. Approximately 56% of Kingsbury Creek has been channelized or straightened (Figure 26). This channelization has also led to bank instability from high flow velocities and resulting erosion (MPCA 2016).

A BANCS assessment conducted on approximately half of the creek shows that 44% of the predicted sediment load from bank erosion is coming from five stream banks (Figure 27). TSS data and the longitudinal snowmelt sampling, however, show that a significant amount of sediment is being sourced upstream of Point Drive, but no BANCS assessment was conducted to support this at this time (MPCA 2016).

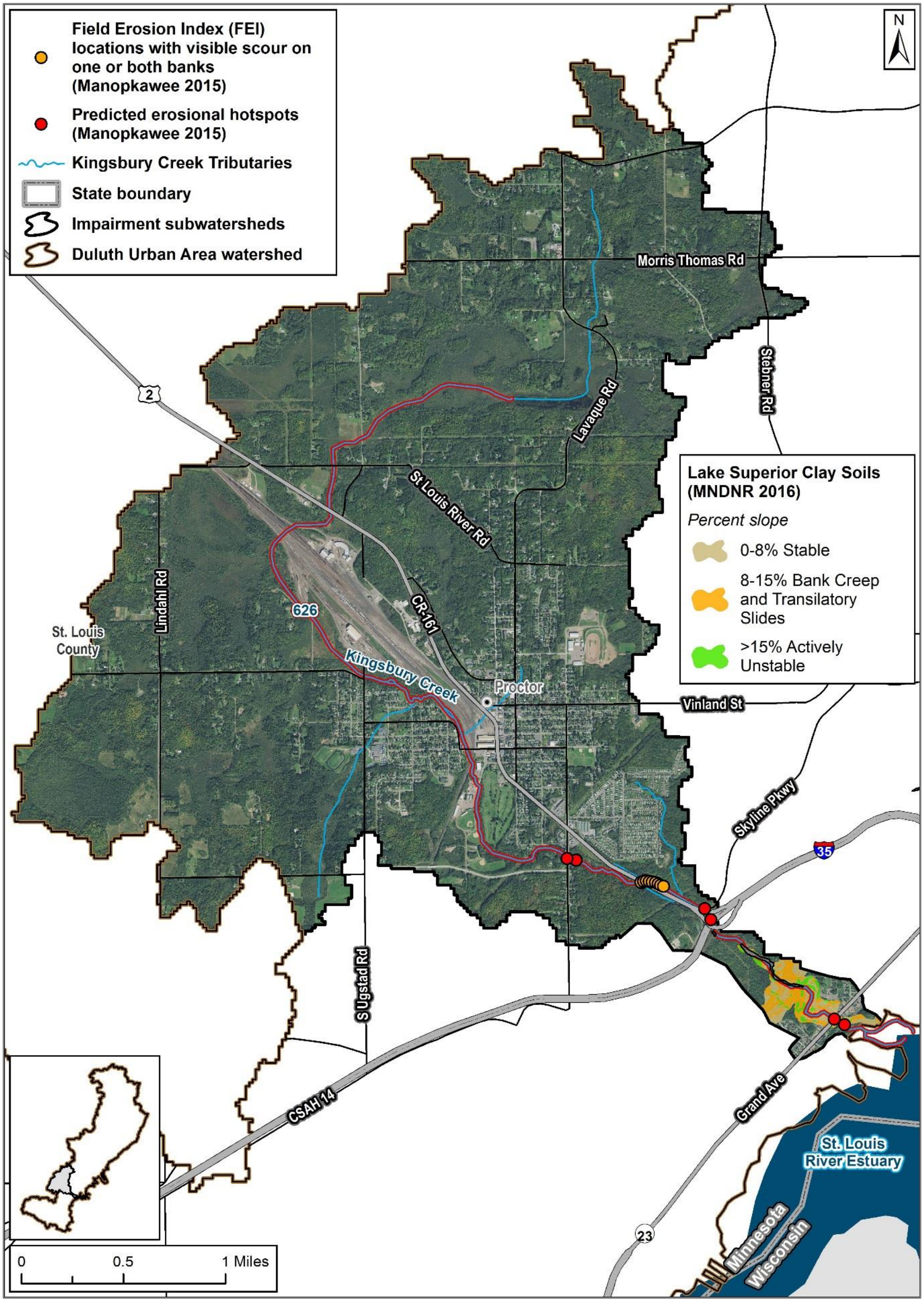


Figure 25. Potential sediment source areas identified in the Kingsbury Creek Subwatershed.

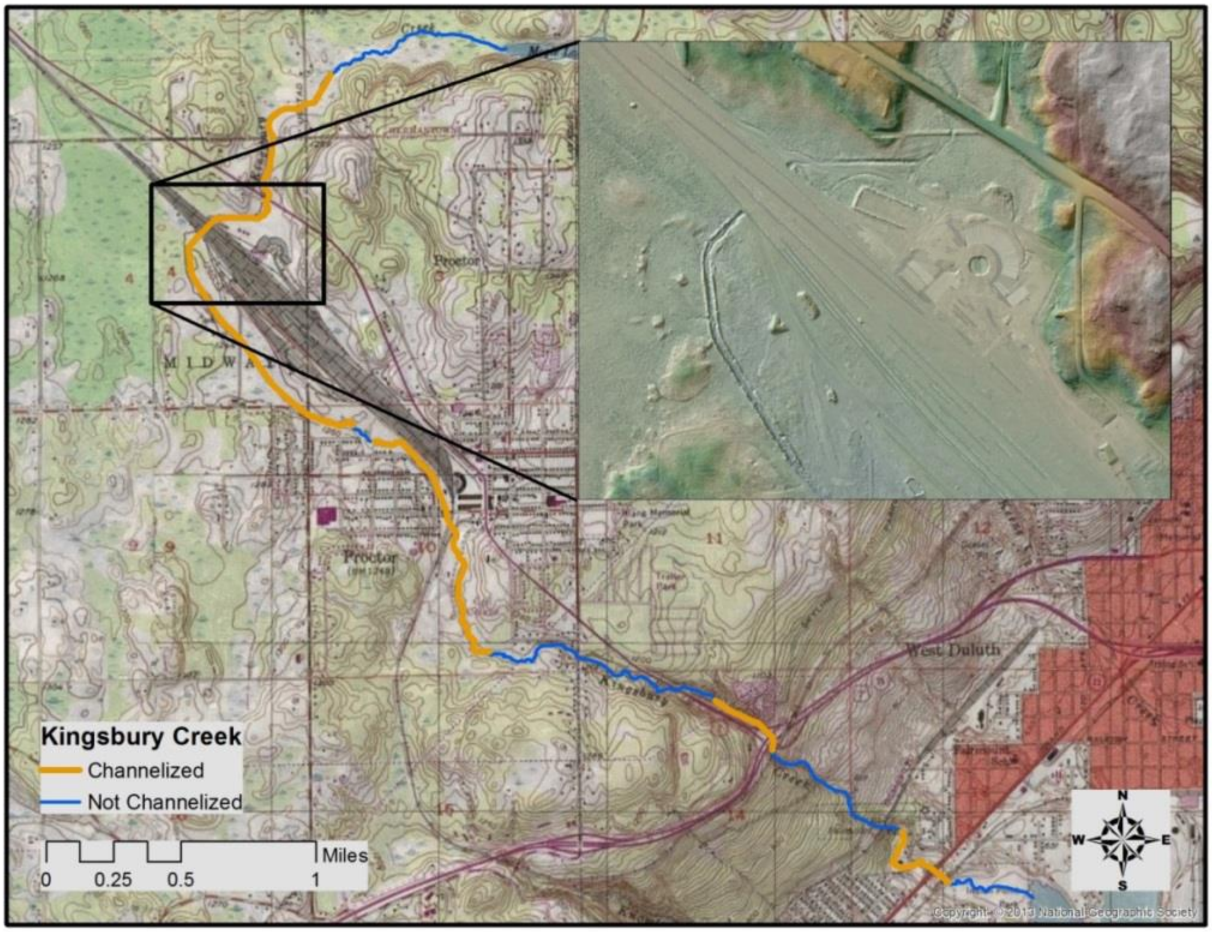


Figure 26. Channelized and straightened reaches of Kingsbury Creek (MPCA 2016).

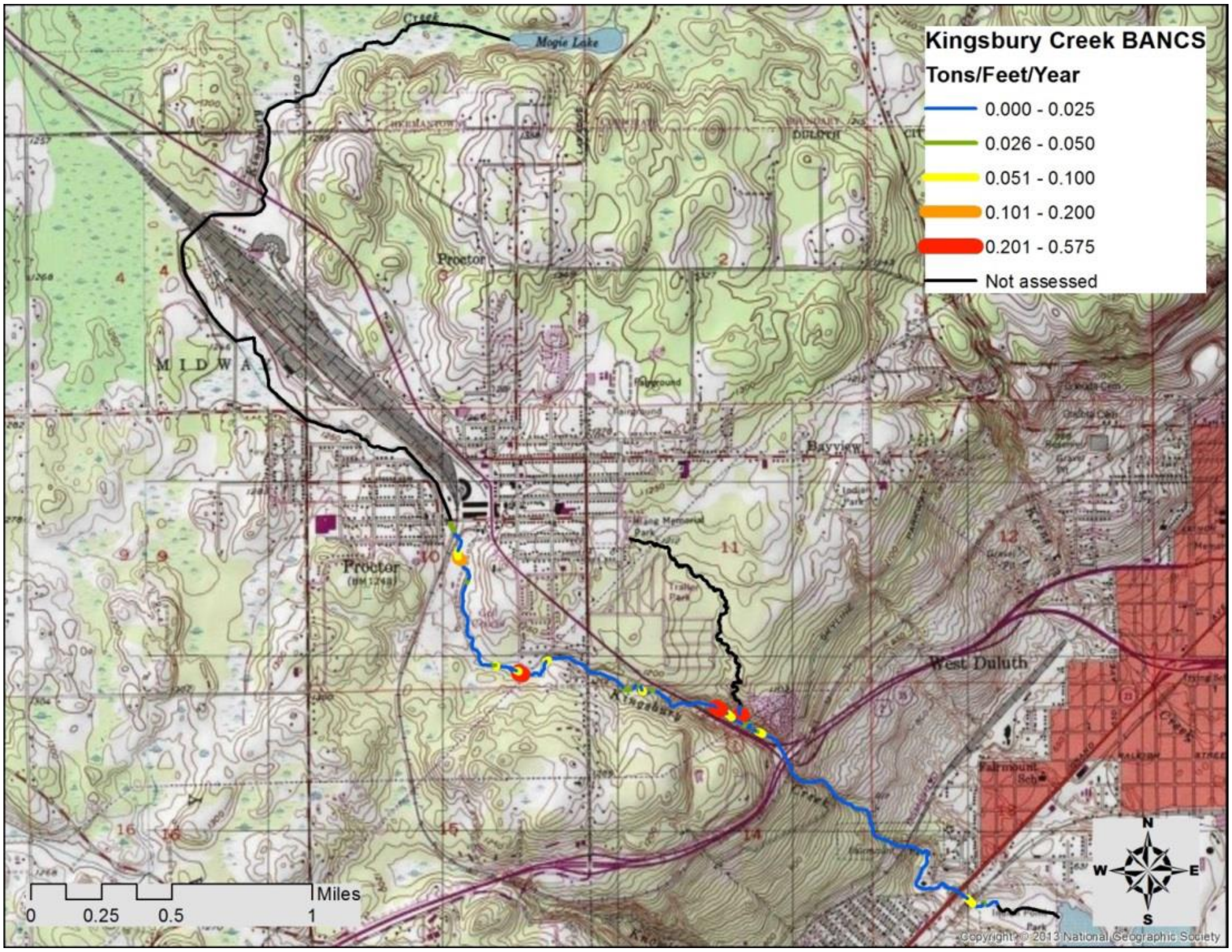


Figure 27. BANCS modeling in Kingsbury Creek (MPCA 2016).

Exceedances analysis

The HSPF model outputs were used to approximate the percent of time the different reaches were exceeding the TSS water quality standard (Tetra Tech 2019). This analysis differs from the assessment information provided in Section 3.3. The data provided in Section 3.3 are used to assess and determine impairment status; the MPCA does not use model outputs to determine official impairment status.

The rates of exceedance in Figure 28 and Figure 29 are based on simulated average daily TSS concentration in the reach for each day during the standard window (April through September) between 1995 and 2016. The TSS standard allows for exceedances of the in-stream concentration (i.e., 10 mg/L) 10% of the time. By using the daily model outputs, we can better evaluate the percent of time when the stream is exceeding the standard and identify reaches of concern that may not have water quality data.

Typically, TMDLs evaluate the exceedances only on days when a grab sample was collected. TSS monitoring data collected between the months of April through September from 2003 to 2016 were tabulated by flow percentile using simulated daily flow from the model. A greater number of samples were collected during higher flows (Figure 30). Since exceedances tend to be associated with higher flows, the TSS criterion exceedance rate calculated from monitoring data is biased high relative to the true exceedance rate. As a result, model predictions of TSS exceedance rates are lower than indicated from sampling data.

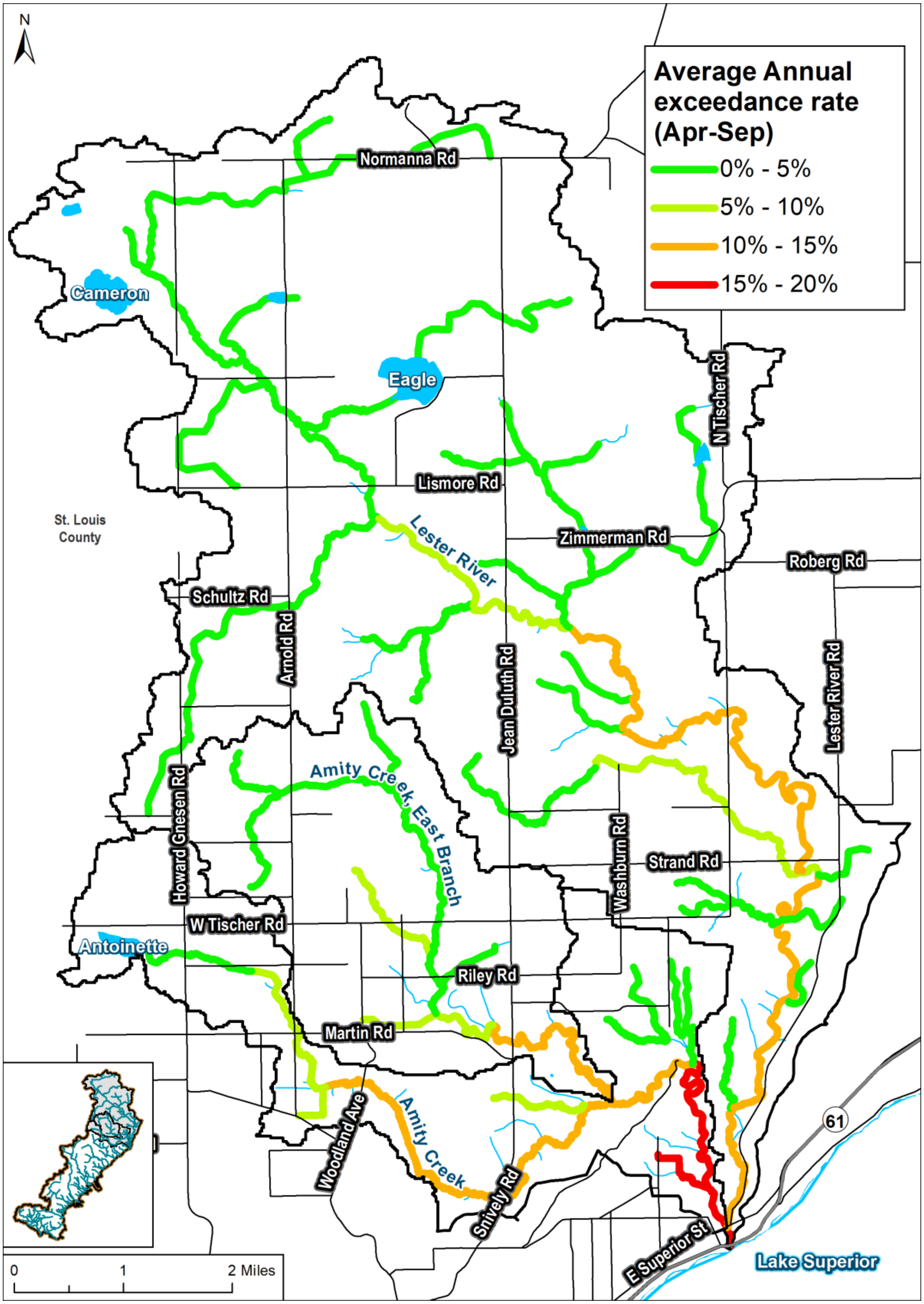


Figure 28. Percent of time TSS water quality standard is exceeded in Lester, Amity, and East Branch Amity during the model simulation (Apr-Sept 1995-2016).

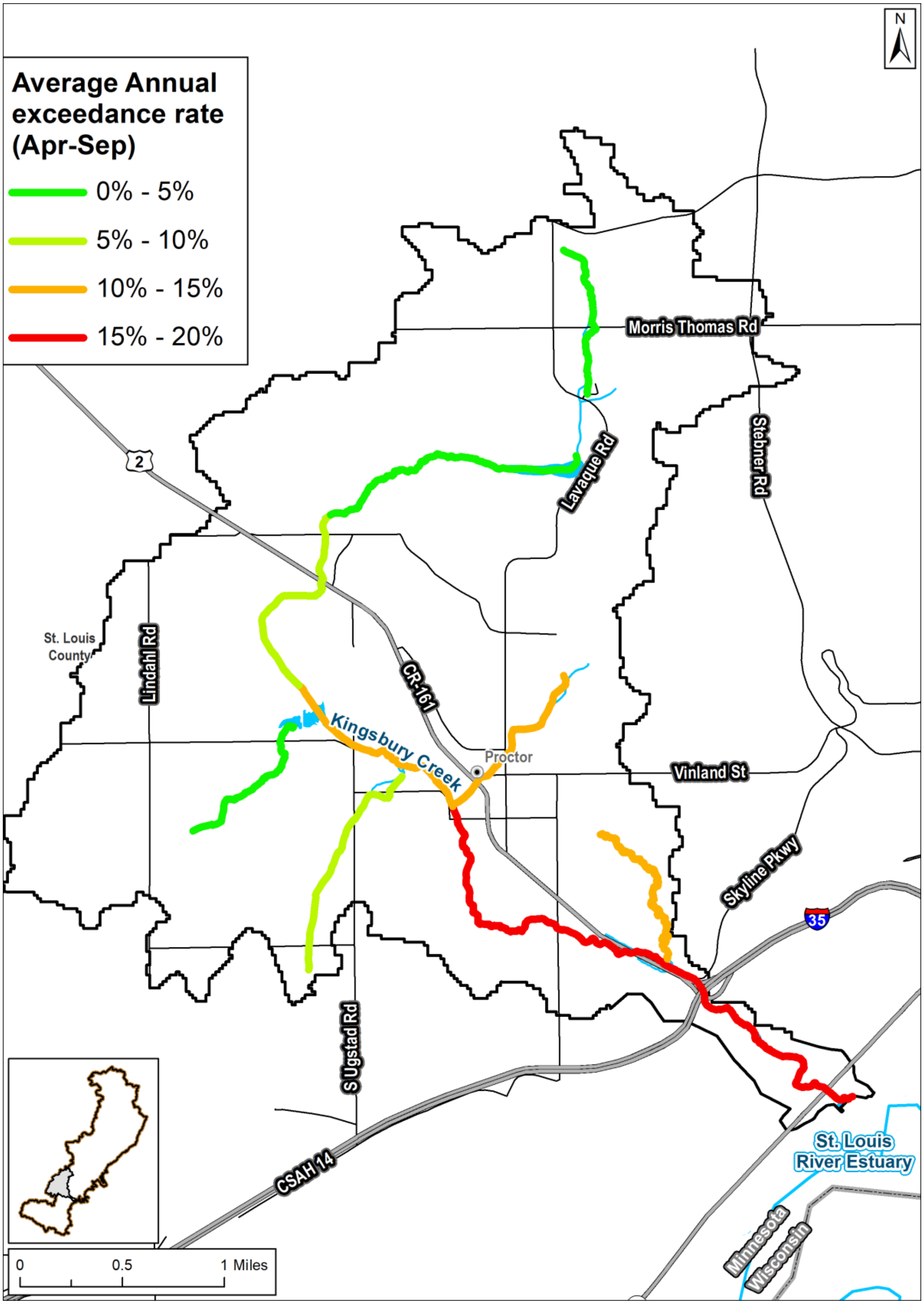


Figure 29. Percent of time TSS water quality standard is exceeded in Kingsbury during the model simulation (Apr-Sept 1995-2016).

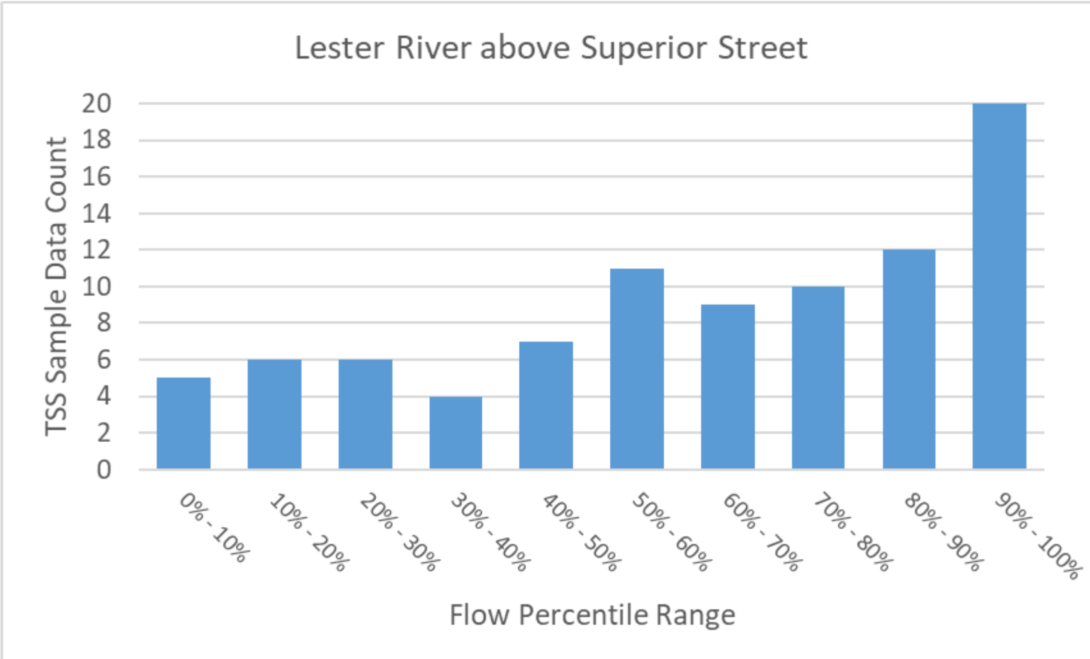


Figure 30. TSS sample count by flow percentile range, Lester River above Superior Street.

Synoptic sampling

Synoptic sampling was conducted throughout the Amity Creek Watershed on four dates: 4/11/2011, 3/20/2012, 5/24/2012, and 9/16/2013 (Lakesuperiorstreams.org 2019; Figure 31-Figure 34). At 27 locations in the watershed, specific electrical conductivity, transparency tube, turbidity, and TSS were monitored within an eight-hour period. Assessments in 2011 and 2012 occurred during high flows. In 2013, sampling was conducted during baseflow conditions.

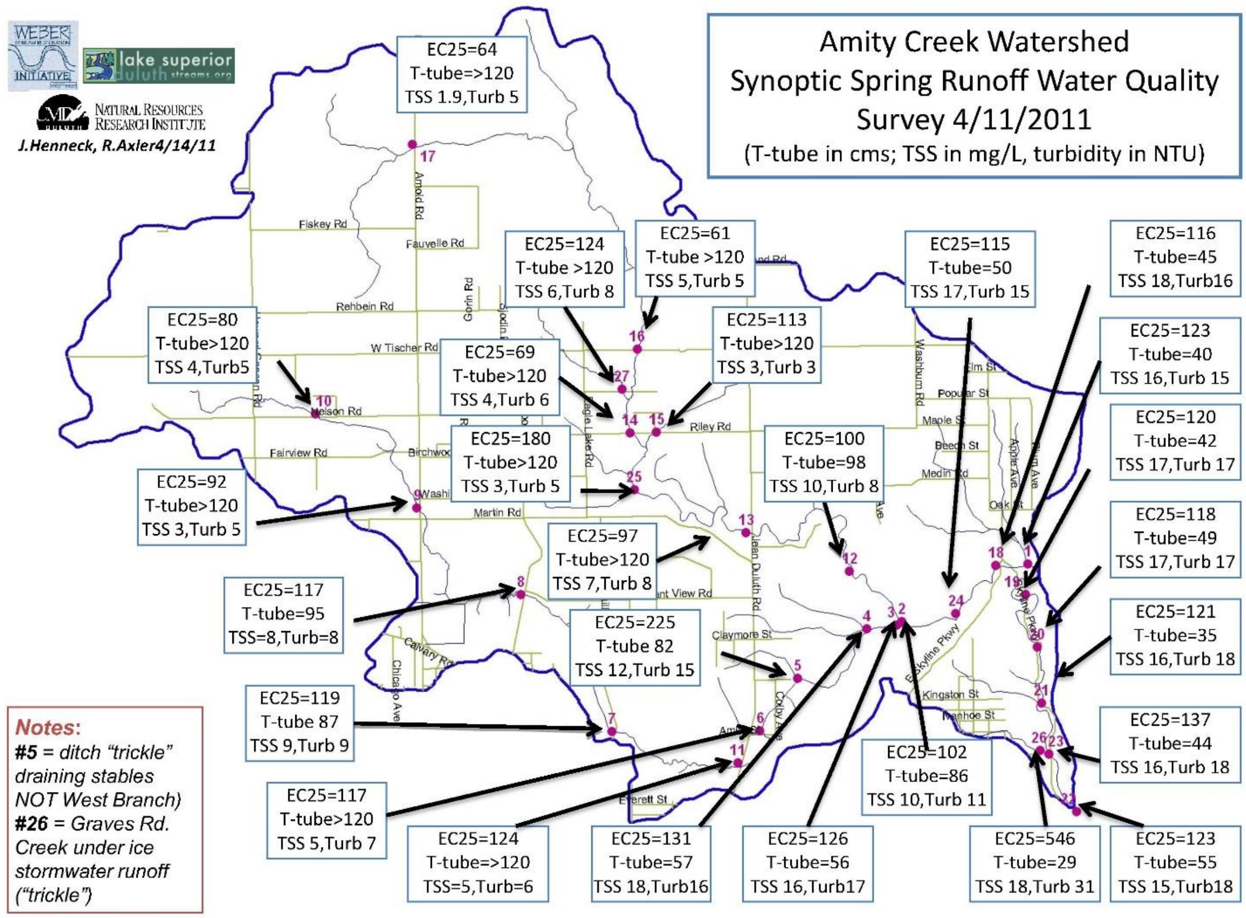


Figure 31. Synoptic sampling results, 4/11/2011.

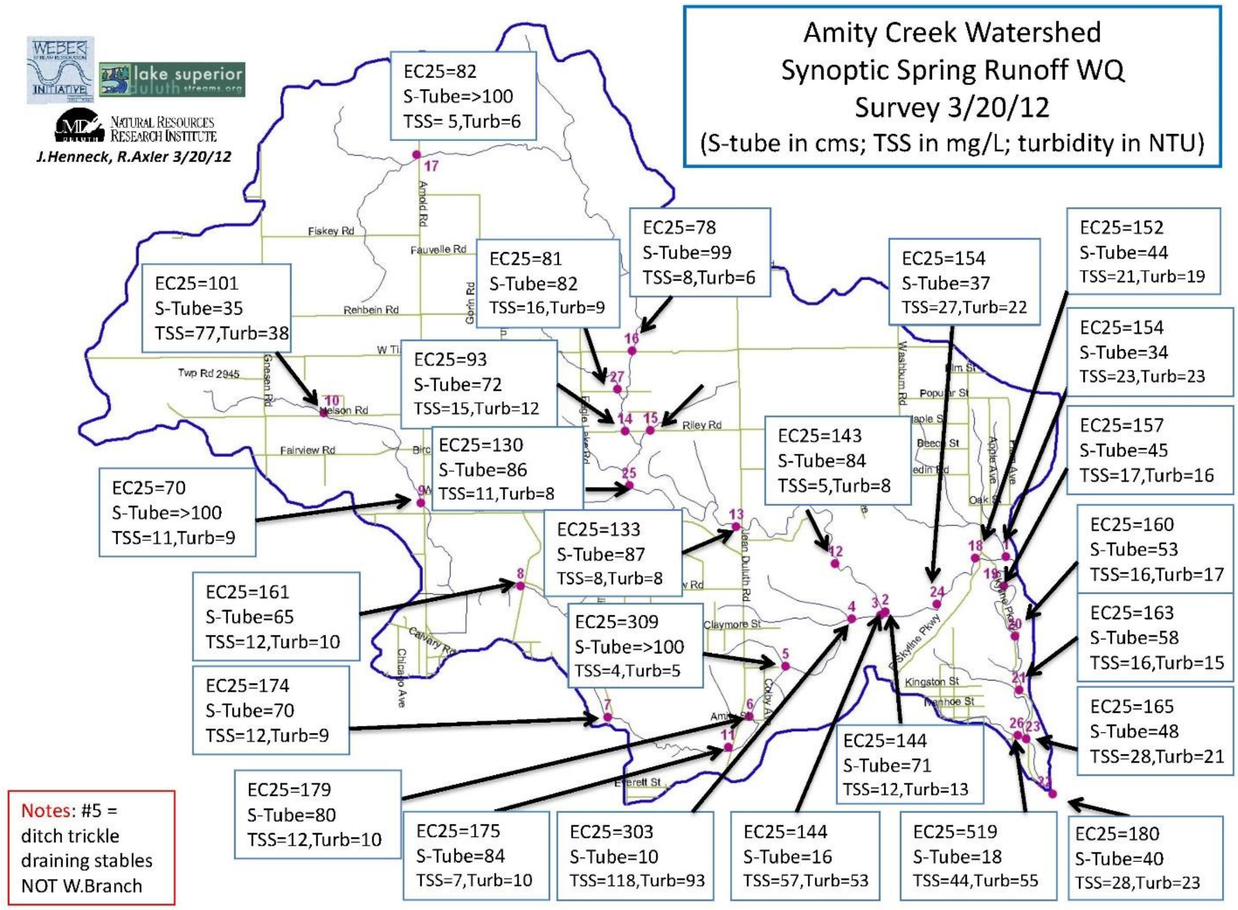


Figure 32. Synoptic sampling results, 3/20/2012.

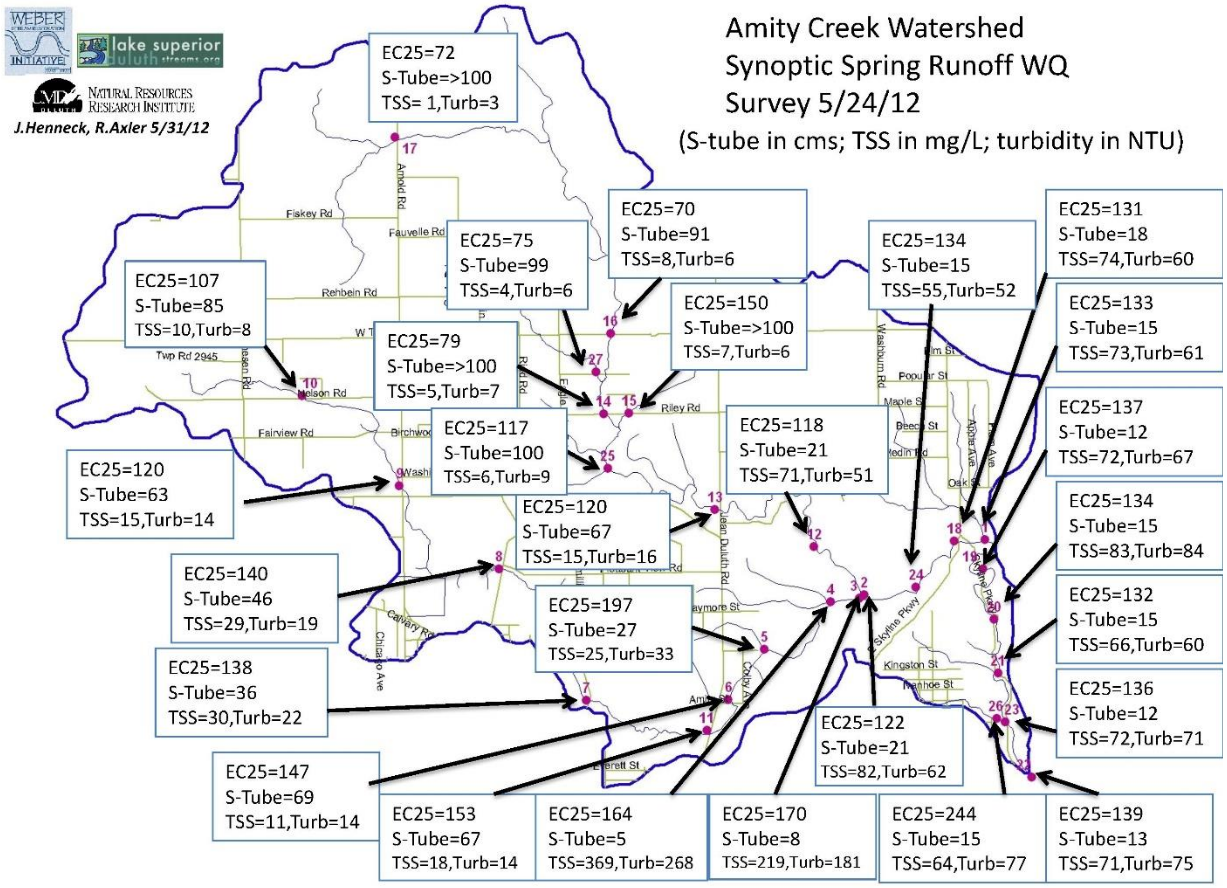


Figure 33. Synoptic sampling results, 5/24/2012.

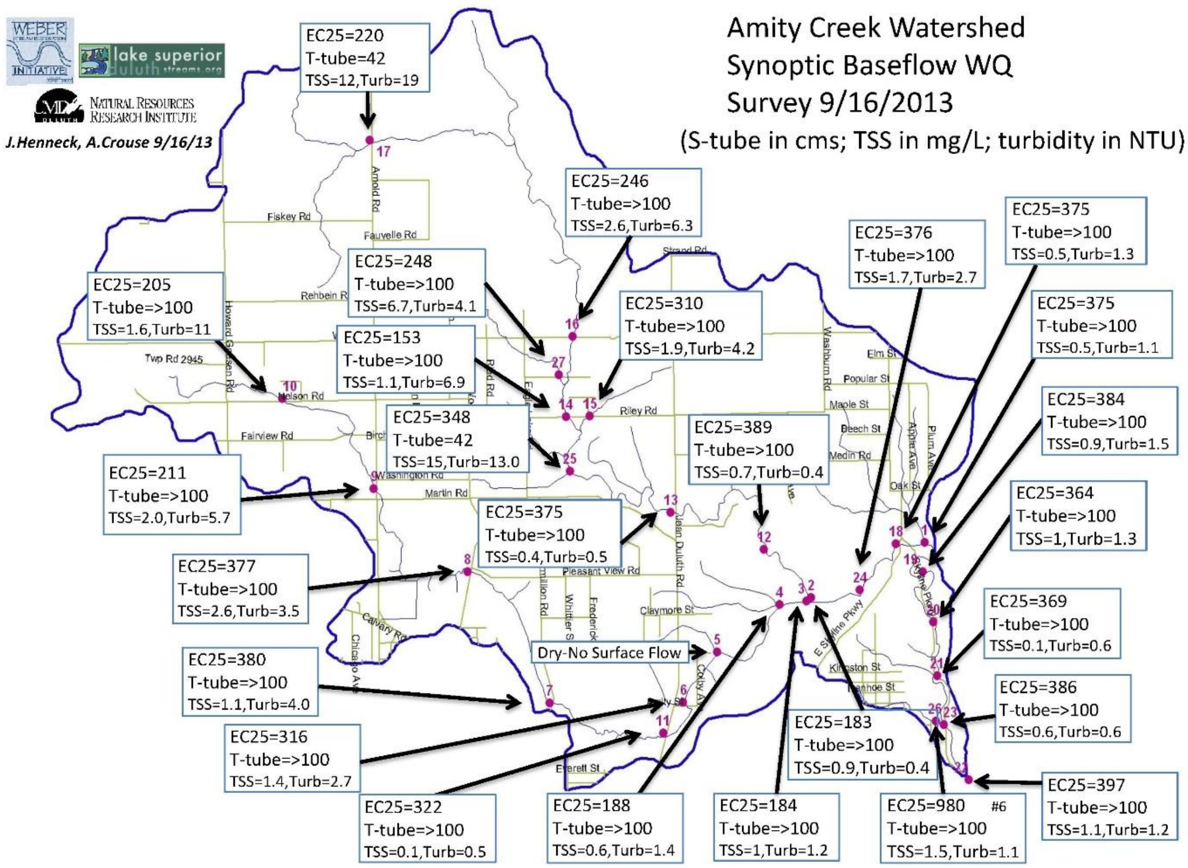


Figure 34. Synoptic sampling results, 9/13/2013.

3.5 *E. coli* Pollutant Source Summary

Chester, Keene, Sargent, Stewart, Tischer, Miller, and Merritt creeks are all impaired due to high levels of *E. coli*. Sources of *E. coli* are widespread and often intermittent. Some sources pose a greater risk to human health than others. Understanding the different source contributions and their potential risk to human health is important to overall TMDL implementation and prioritizing implementation activities that address the recreational use impairments due to *E. coli*. The *E. coli* source assessment evaluated permitted and nonpermitted source loads from humans, livestock, wildlife, and domestic pets. Potential sources were identified through the MPCA permit information and monitoring records, county and municipal records, watershed and stream-specific studies and data, and field data. A weight of evidence approach was used to determine the primary sources of *E. coli*.

Sources of *E. coli* are also often associated with sources of sediment, therefore sources described in Section 3.4 should also be considered potential sources of *E. coli*. Sediment can also contain naturalized *E. coli* (C. Hakala, MDH, personnel communications).

Die-off or instream growth of *E. coli* was not explicitly addressed. However, *E. coli* strains can become naturalized components of the soil microbial community (Ishii et al. 2006) and have been found in ditch sediment in the Seven Mile Creek Watershed, Minnesota (Sadowsky et al. n.d., Chandrasekaran et al. 2015). The ultimate origin of the naturalized bacteria is unknown.

Microbial source tracking (MST) is a useful tool to help differentiate sources of *E. coli*. Fecal Bacteroidetes, or fecal indicator bacteria, are used in MST. Human markers along with a variety of other bird and animal markers can be identified. In 2016-17 MST was used to assess sources of fecal bacteria at beaches in the St. Louis River Area Of Concern, described below, and in 2020 is being used by Duluth staff to evaluate sources of fecal bacteria in Tischer Creek and Keene Creek. The results of this work may further inform the sources of *E. coli*. A similar study in Minneapolis found that in urban areas sources of *E. coli* include lawns and grassy areas along parkways, stream sediment, streambank and riparian sediment, road construction activity, organic debris in street gutters, and improperly managed temporary toilets (Burns and McDonnell 2017 Draft).

3.5.1 Results from the Bacterial Source Tracking at Impaired Beaches in the St. Louis River Area of Concern final report

The *Bacterial Source Tracking at Impaired Beaches in the St. Louis River Area of Concern* final report (Prihoda et al. 2017) included evaluation of sources in Chester Creek and Stewart Creek from May through September in 2015 and 2016. The work included looking at human, gull, and ruminant (e.g., deer) markers at one sampling location on Chester Creek (mouth of creek, Figure 35) and two sampling locations along Stewart Creek (mouth of creek and upstream near Smithville Park, Figure 36).

Chester Creek

Seventeen samples were selected for DNA analysis; each sample exceeded the beach water quality *E. coli* standard. Human DNA markers were detected in 94% of the samples and 25% of the samples had human DNA marker concentrations above the benchmark used to detect the presence of human fecal contamination. Chester Creek was identified as a high priority for determining how to reduce human health risk at Leif Erikson beach. Ruminant DNR markers were detected in one of the samples selected for DNA analysis and gull markers were detected in three samples.

Figure 35. Sampling location at mouth of Chester Creek for the Leif Erikson Beach bacterial source assessment (Prihoda et al. 2017).

Stewart Creek

The bacterial source tracking study did not have sufficient data to draw definitive conclusions on the source or origin of *E. coli* in and around Stewart Creek. Results from the Stewart Creek monitoring and analysis, however, do suggest that *E. coli* from a human source may be sourced at a location downstream from the Smithville Park sampling location, as results at the mouth of Stewart Creek expressed the human signal more frequently than the upstream location.

In addition, sanitary surveys conducted during the Prihoda et al. (2017) study often noted a sewage odor during collection of samples at the Smithville Park location; however, active sewage run-off was never observed at or near Stewart Creek. The study notes that the odor could be from the Cloquet Pumping Station located on Knowlton Creek, which is less than two miles to the northeast of the sampling location. The Cloquet Pumping Station receives all of the waste from the local paper mills, which creates a definite odor. Further investigation was recommended.

Ruminant DNA markers were detected in one upstream sample site near Smithville Park. No gull DNA markers were detected in any of the samples that were selected for DNA analysis for the Stewart Creek locations.

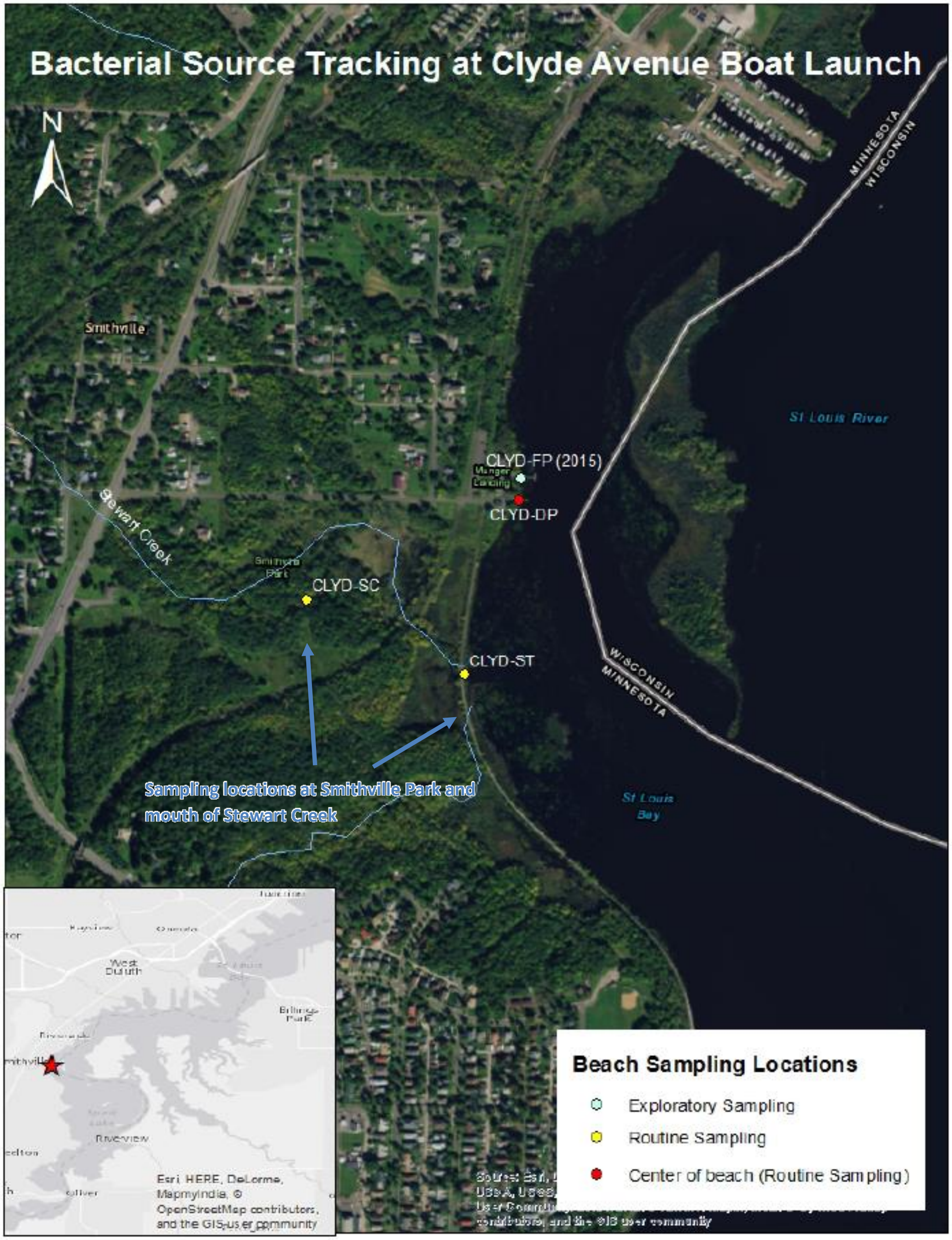


Figure 36. Sampling locations along Stewart Creek for the Clyde Avenue Beach bacterial source assessment (Prihoda et al. 2017).

3.5.2 Permitted Sources

The only permitted sources of *E. coli* in the impairment subwatersheds are regulated MS4s (see Section 3.4.1). Whereas stormwater runoff is not an actual source of *E. coli* to surface waters, it acts as an important delivery mechanism of multiple *E. coli* sources including humans, wildlife, and domestic pets. Stormwater runoff from impervious areas (such as roads, driveways, and rooftops) can directly connect the location where *E. coli* is deposited on the landscape to surface waters. For example, there is a greater likelihood that uncollected pet waste in an urban area will reach surface waters through stormwater runoff than it would in a rural area with less impervious surfaces. Wildlife, such as birds and raccoons, can be another source of *E. coli* in urban stormwater runoff (Wu et al. 2011, Jiang et al. 2007).

The MPCA stormwater wiki (https://stormwater.pca.state.mn.us) provides the following information as related to fecal bacteria in stormwater, specifically from roads:

- Residential lawns, driveways, and streets are the major source areas for fecal bacteria, while rooftops and parking lots are usually smaller source areas. Irrigated lawns, in particular, are high contributors.
- Sartor and Gaboury (1984) reported nearly 92% of the fecal bacteria originated from streets in the residential-institutional land use site, whereas only about 33 and 19% of the fecal bacteria originated from streets in the industrial and commercial land use sites, respectively.
- Bannerman et al. (1993) reported that 78% of the fecal coliform bacteria load for a residential land use study originated from streets.

3.5.3 Nonpermitted Sources

Nonpoint sources of *E. coli* may include human sources (e.g., failing septic systems, leaky wastewater infrastructure), non-MS4 stormwater runoff, pets, wildlife, and livestock.

Human sources

Although the majority of the watershed is urbanized and wastewater is treated by a regional treatment plant, septic systems are still found in the less developed areas, and also within the developed portions when homes are not connected to regional sewer services. Septic systems that function properly do not contribute *E. coli* to surface waters. Failing septic systems that discharge untreated sewage to the land surface are considered an imminent threat to public health and safety (ITPHS) and can contribute *E. coli* to surface waters. Clay soils and shallow depth to bedrock found in the watershed can increase the likelihood of failing septic systems.

The *E. coli* load from ITPHS septic systems can be estimated based on county compliance rates and total number of subsurface sewage treatment systems. St. Louis County provided the number of septic system inspections and the total non-compliant and ITPHS systems observed during inspections by city and township (Table 31; provided February, 4, 2019 by St. Louis County).

Table 31. St. Louis County septic system inspections (2002-present).

City or Township	Number of Septic System Inspections	Number of Non-compliant Systems	Number of ITPHS Systems	Non-compliant or ITPHS (%)
City of Duluth	313	25	3	9
City of Hermantown	512	41	0	8
Midway Township	149	21	0	14
City of Proctor	28	4	0	14
City of Rice Lake	428	41	3	10

The number of septic systems in the *E. coli* impairment watersheds was estimated using information provided by the City of Hermantown on parcels that are connected to sanitary sewer, St. Louis County parcel database and associated databases. Any parcel within the city of Hermantown that is not identified as connected to sanitary sewer was assumed to have a septic system. For all remaining areas, information provided by St. Louis County was used to select parcels not connected to sanitary sewer. Figure 37 identifies parcels in the *E. coli* impairment watersheds that are estimated to have septic systems (Table 32).

Table 32. Number of septic systems per *E. coli* impaired watershed.

Impaired Segment	Estimated Number of Septic Systems
Chester Creek	140
Keene Creek	117
Merritt Creek	17
Miller Creek	127
Sargent Creek	49
Stewart Creek	37
Tischer Creek	479

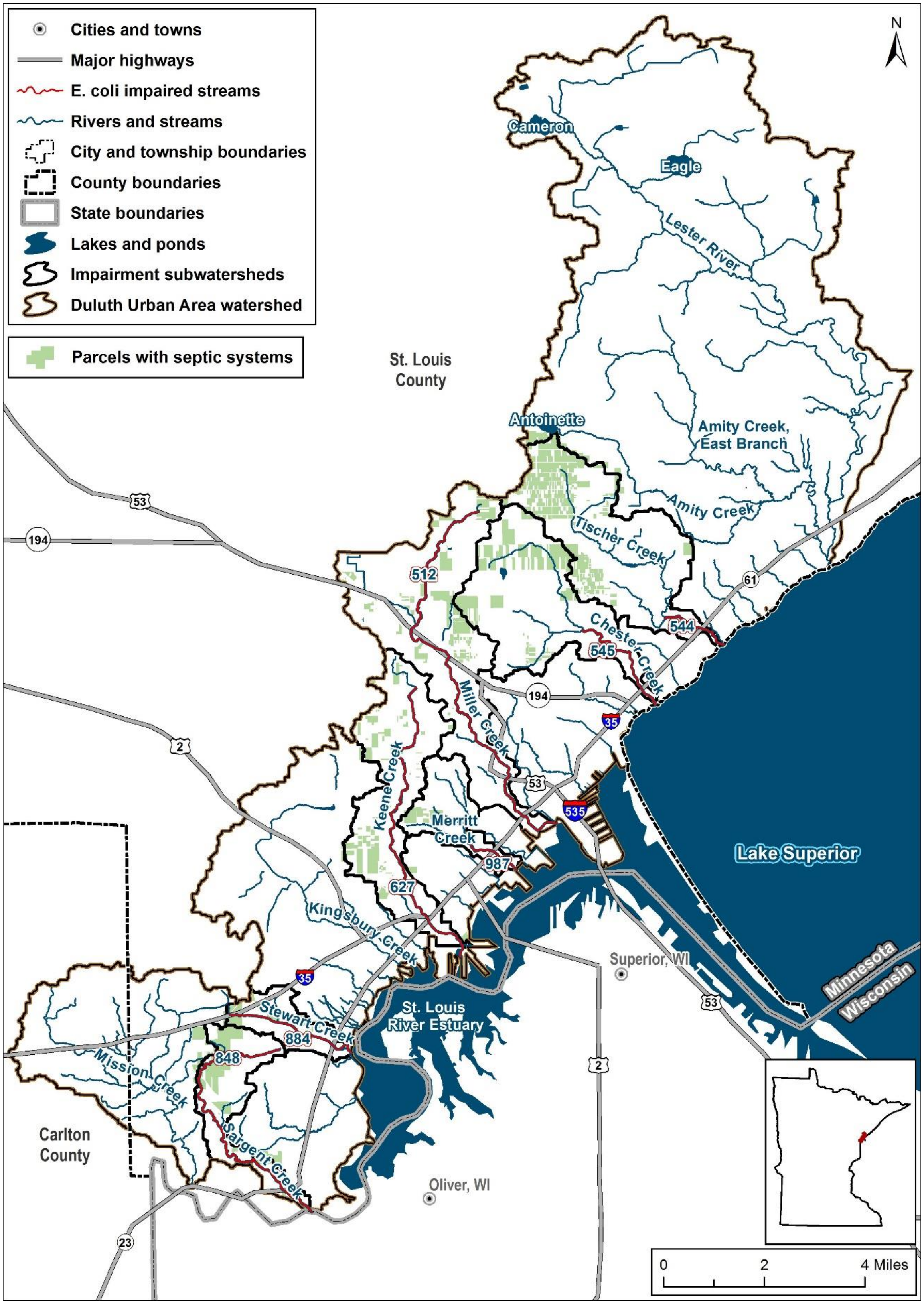


Figure 37. Parcels in *E. coli* impaired watersheds determined to likely have a septic system.
Parcels were retrieved 1/18/2019.

Other human sources of *E. coli* in the watershed include leaky wastewater infrastructure, exfiltration, and sewer backups. As part of the source assessment process, the City of Duluth provided helpful insights into sanitary sewer and other potential infrastructure related sources of *E. coli* (Figure 38 to Figure 44). A large portion of the city's sanitary sewer is composed of vitrified clay. Both the age and material of these pipes increase the likelihood of wastewater leaks into the environment, becoming a potential source of *E. coli* for impaired streams. Duluth has focused on evaluating, lining and upgrading sanitary sewer lines that cross stream channels; these upgraded crossings are identified in Figure 38 to Figure 44.

Additional information on the existing sanitary system and sanitary sewer overflows and backups, known leaky sanitary sewers, and the results of sanitary sewer video inspections were also requested from Duluth, Rice Lake, and Hermantown. Duluth has been conducting video of the sanitary system; however, there were no available summary reports, findings or recommendations that could be provided. Rice Lake and Hermantown provided location information on the sanitary sewers in their communities.

In addition, limited bathroom facilities are available in parks mainly due to vandalism concerns, and there are known populations of homeless individuals who occupy makeshift campsites in floodplains of Duluth's urban streams. These populations often do not have access to bathroom facilities.

Providing a quantitative load of *E. coli* from this source is not possible based on the available data.

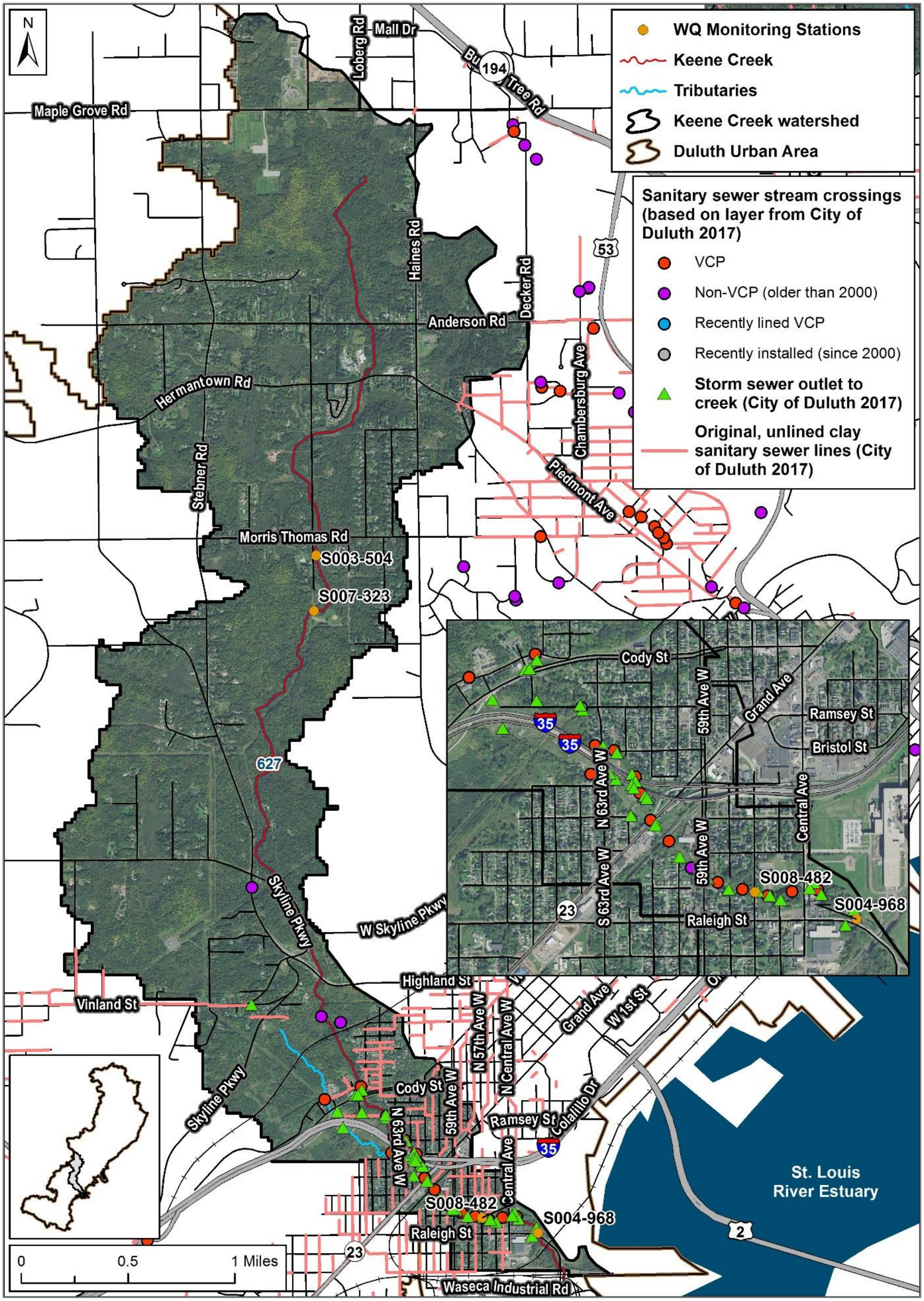


Figure 38. Potential wastewater infrastructure sources of *E. coli* in Keene Creek.

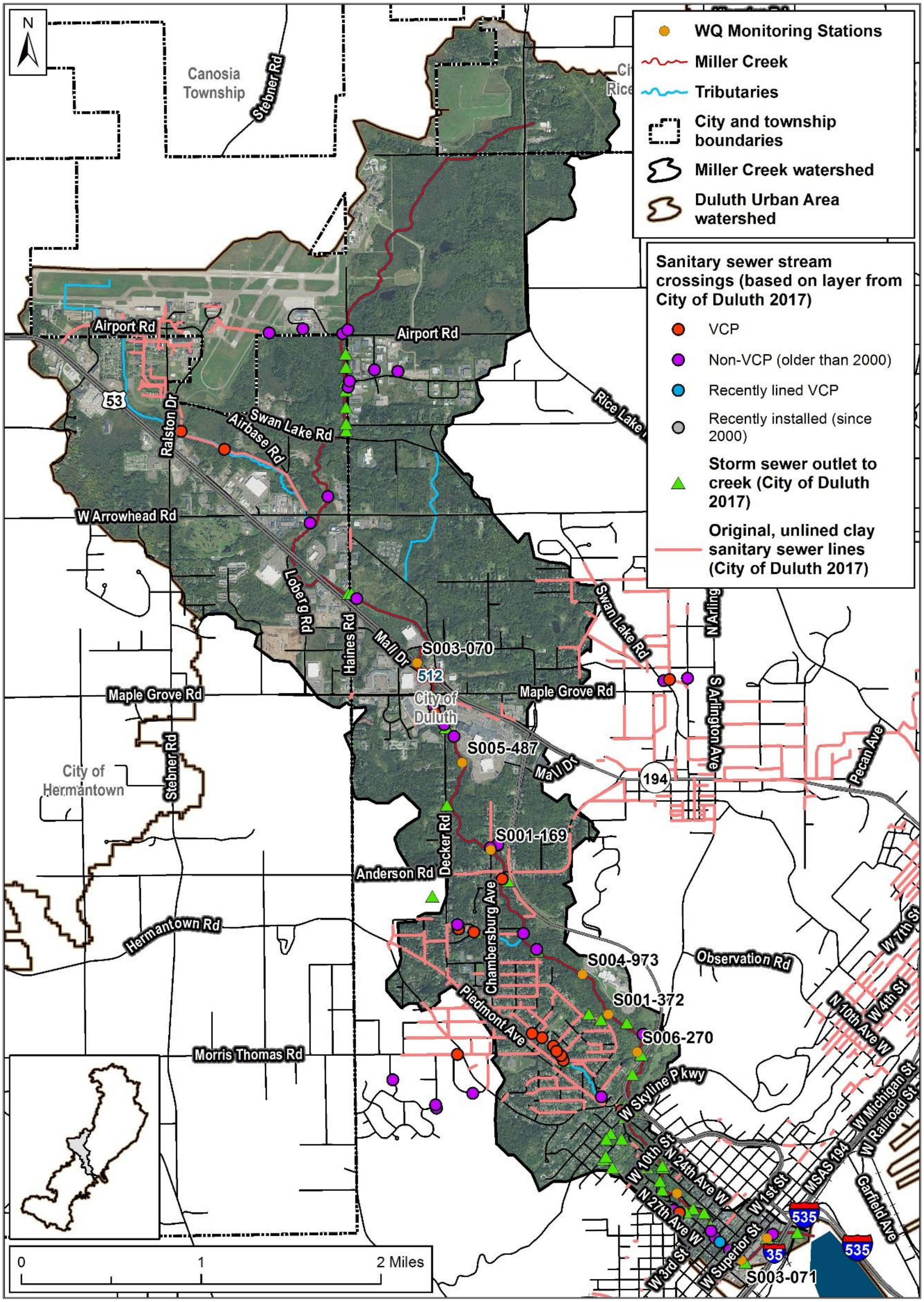


Figure 39. Potential wastewater infrastructure sources of *E. coli* in Miller Creek.

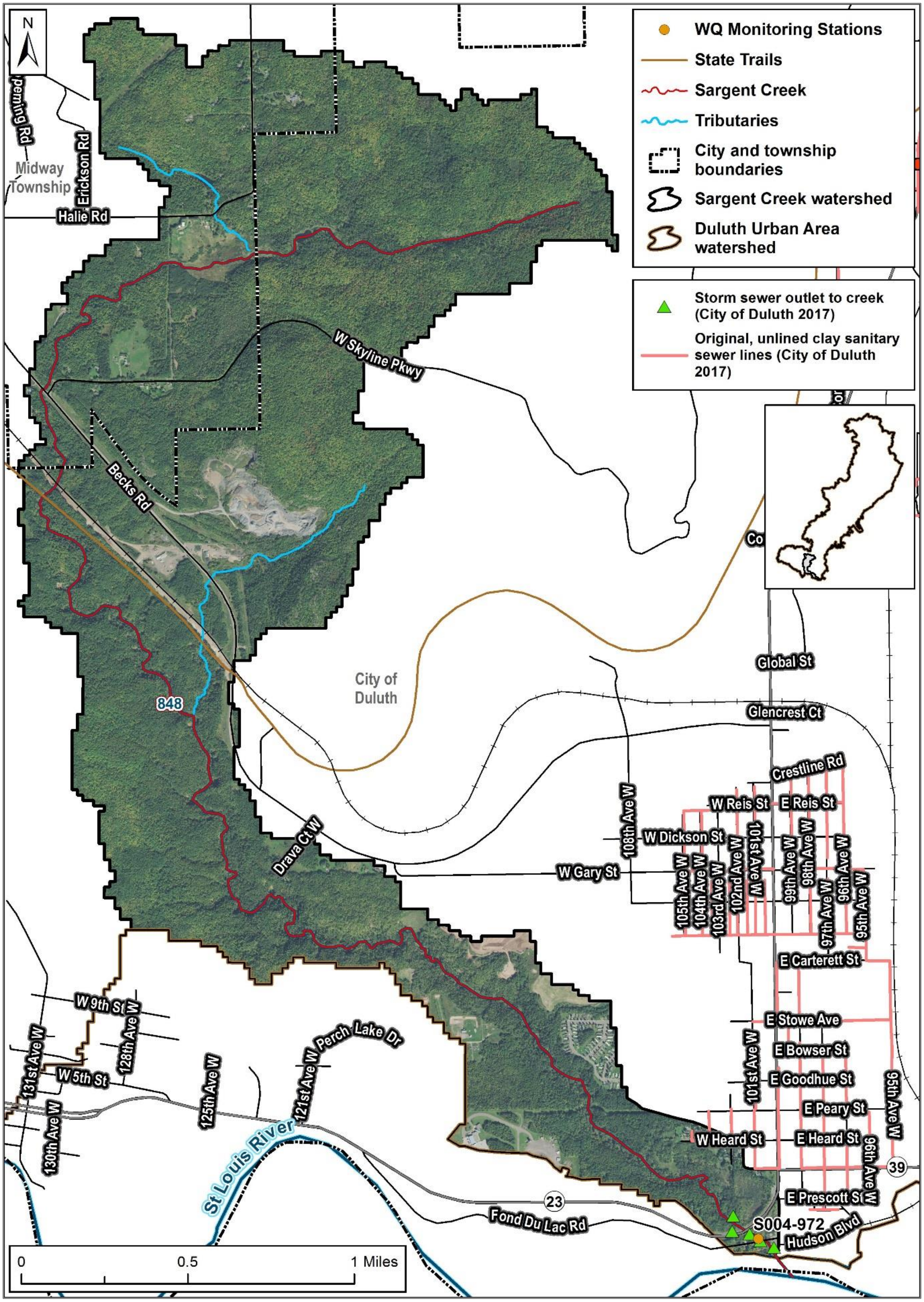


Figure 40. Potential wastewater infrastructure sources of *E. coli* in Sargent Creek.

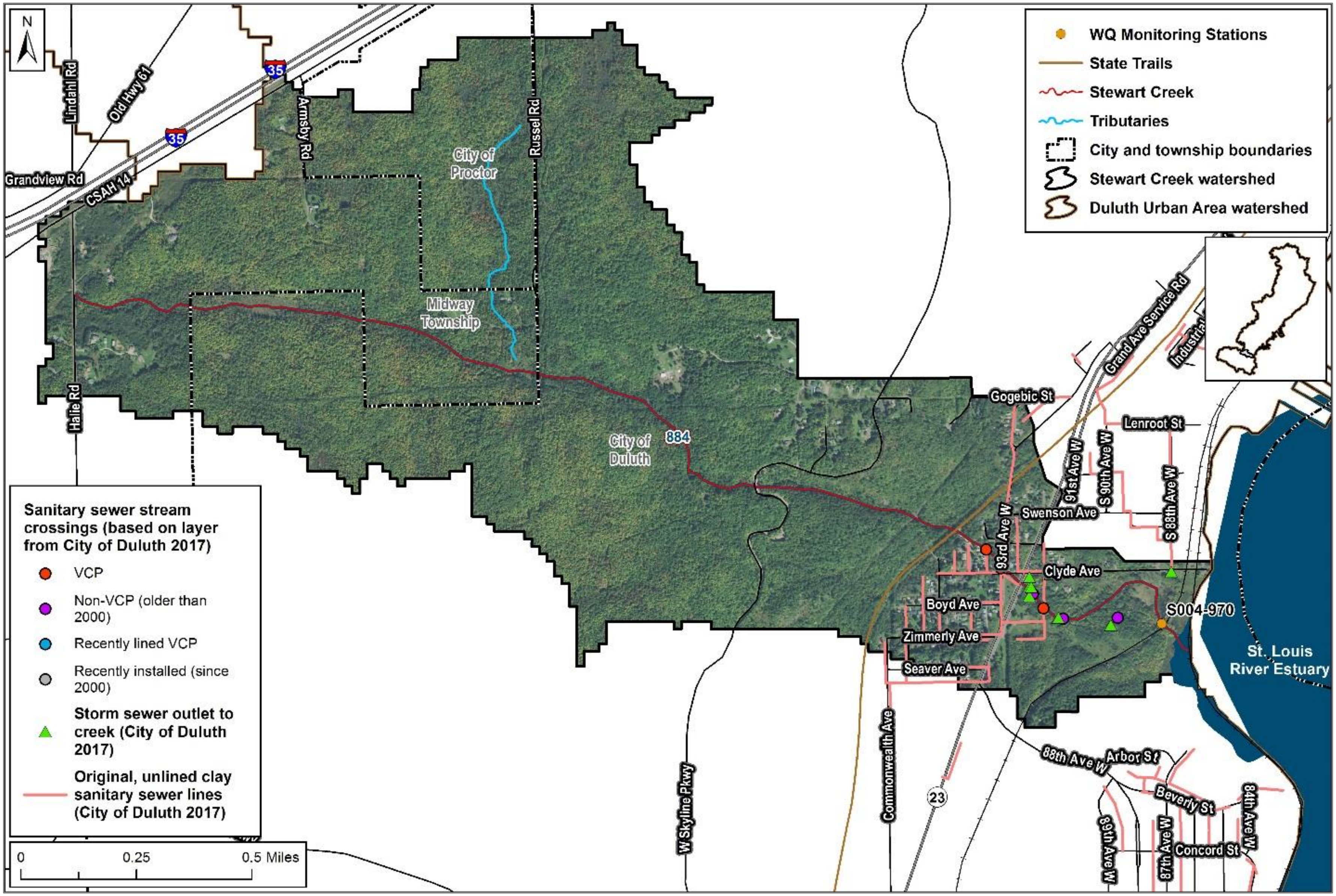


Figure 41. Potential wastewater infrastructure sources of *E. coli* in Stewart Creek.

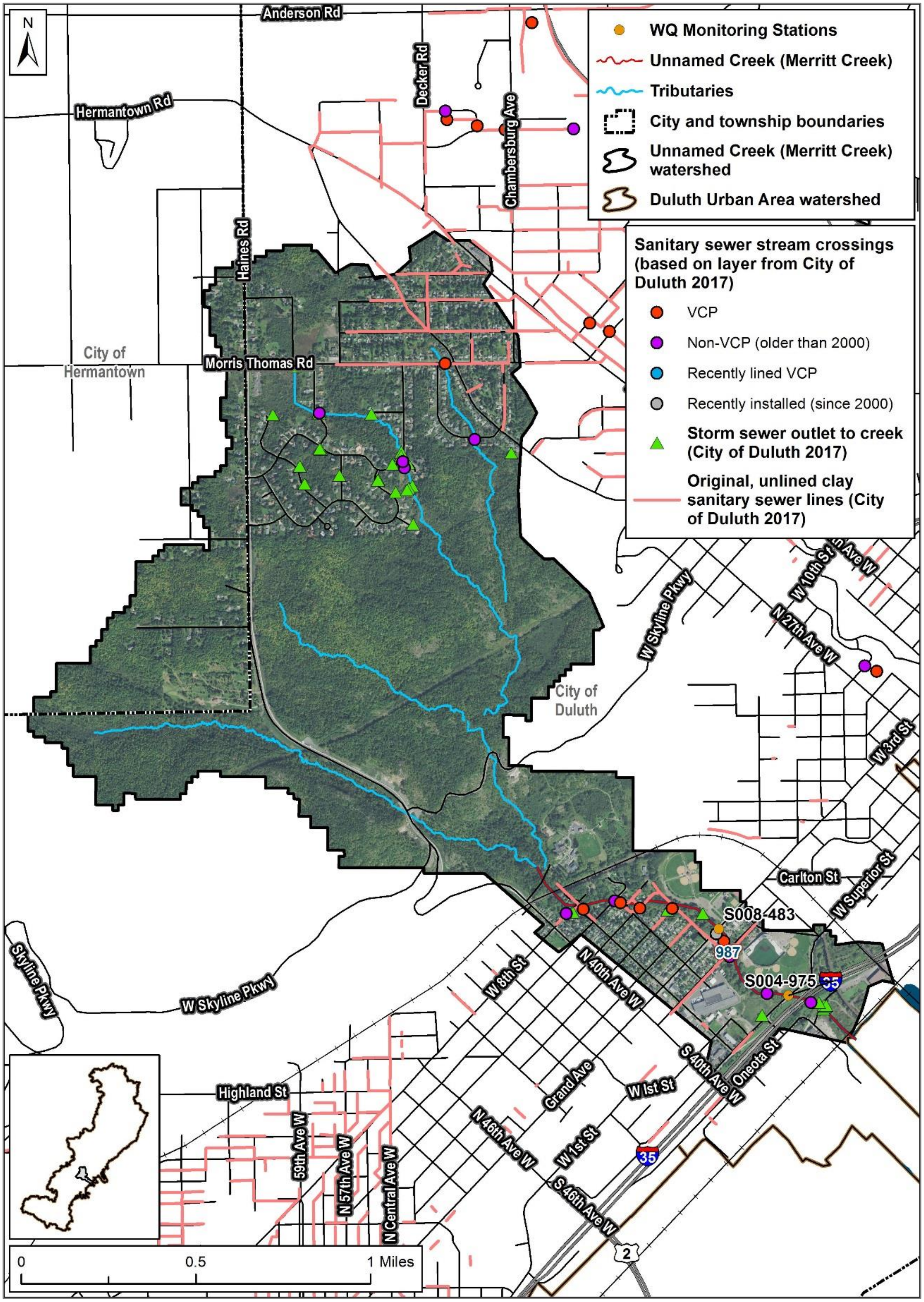


Figure 42. Potential wastewater infrastructure sources of *E. coli* in Merritt Creek.

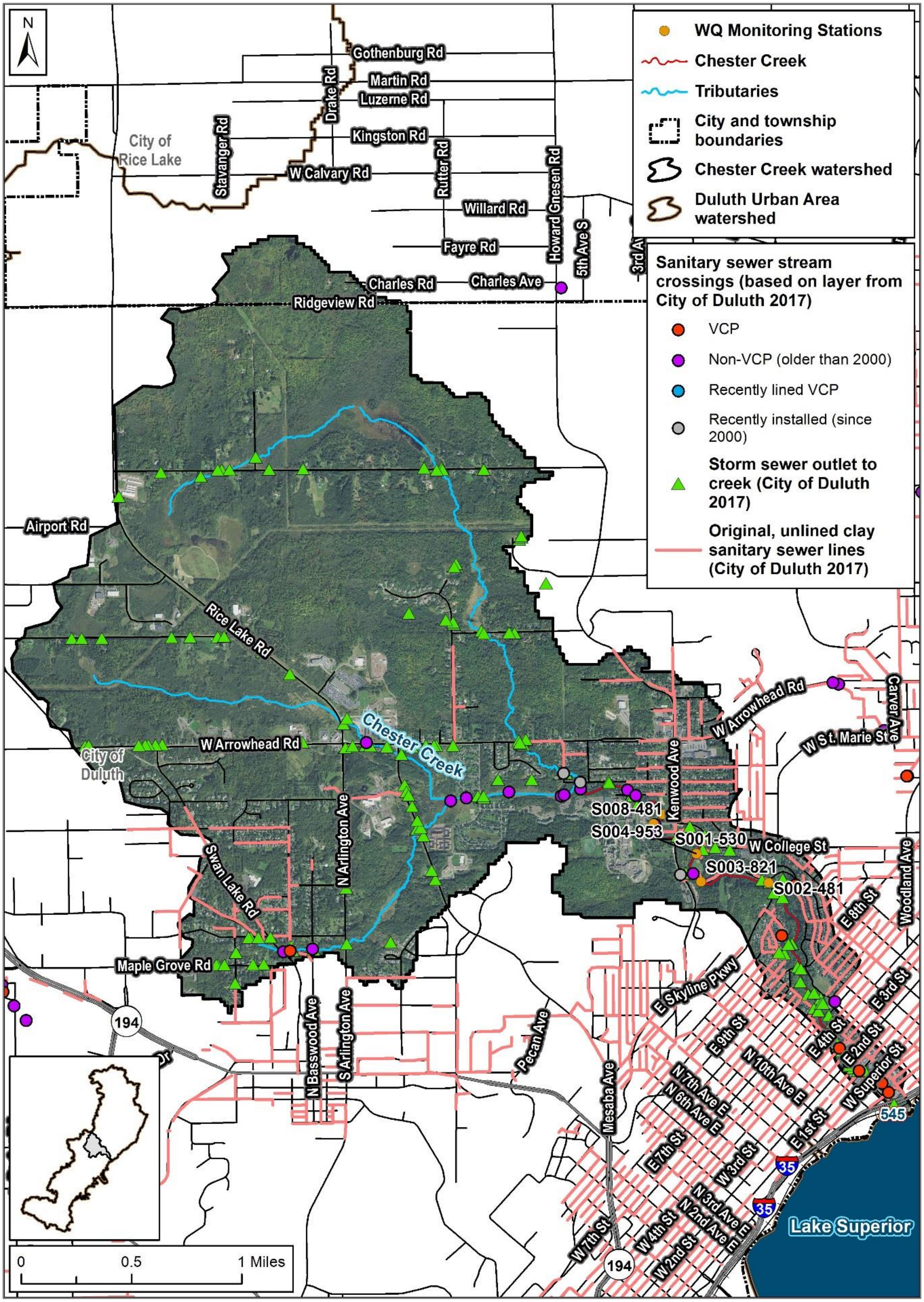


Figure 43. Potential wastewater infrastructure sources of *E. coli* in Chester Creek.

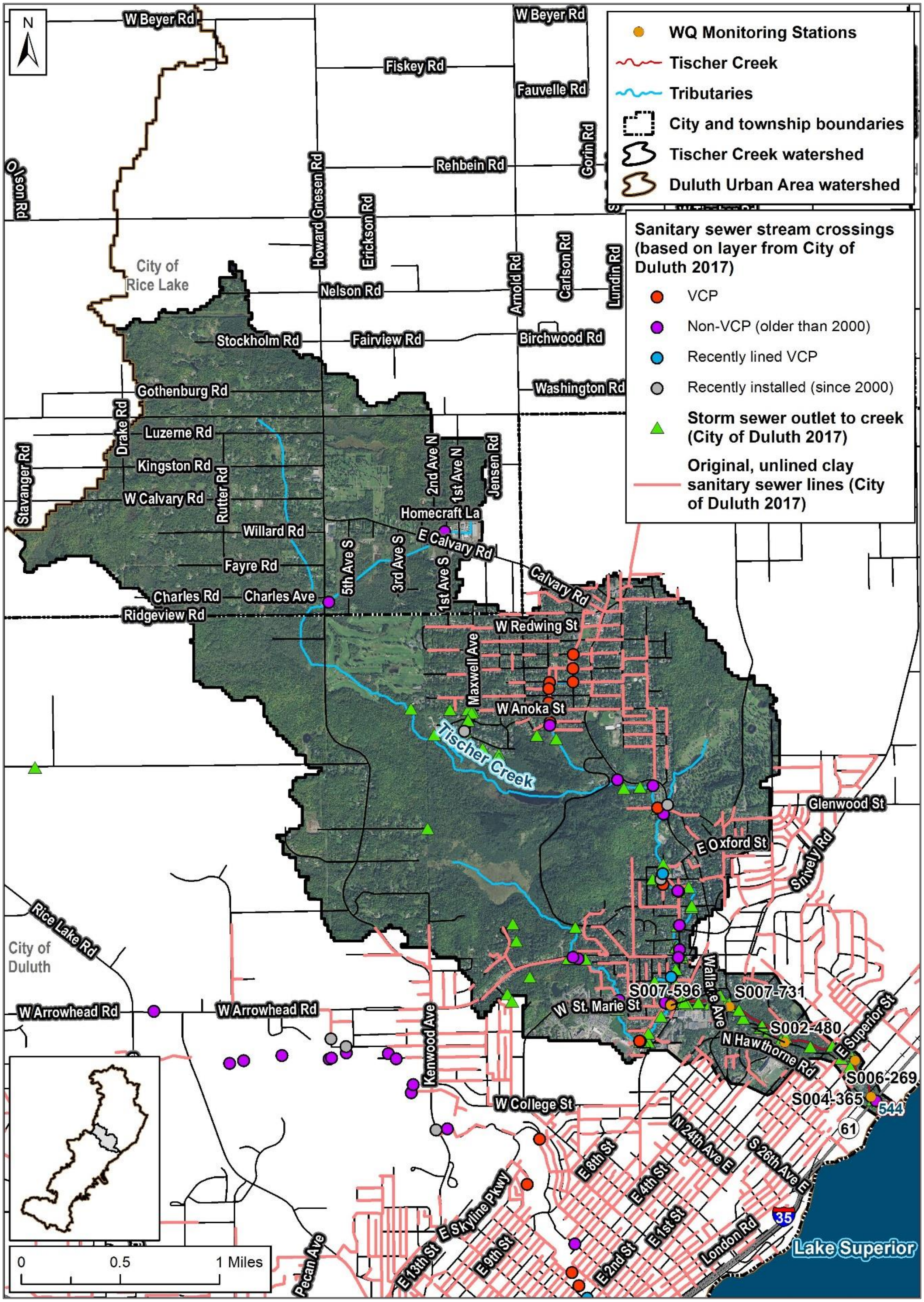


Figure 44. Potential wastewater infrastructure sources of *E. coli* in Tischer Creek.

Stormwater

Stormwater runoff in unregulated areas (outside of regulated MS4 areas) also potentially contributes to impairments, as discussed in the Permitted Sources section above. The location of storm sewer outfalls to each of the impaired streams are included in Figure 38 to Figure 44.

Pets

Pet waste is tied to stormwater runoff as described in the Permitted Sources section above. Pet licensing data were used to approximate the number of pets in each community. Pet licensing data were provided by the cities of Duluth and Proctor; data were not provided by the cities of Hermantown and Rice Lake. Pet numbers for those two communities were calculated using the ratio of pets to population from the City of Proctor data. Pet densities then were calculated per square mile for each community. Pet densities for each community were area weighted to determine an approximate number of pets in each subwatershed (Table 33).

The City of Duluth processes pet licenses for both cats and dogs. Cats can be indoor or outdoor pets; therefore, the calculated number of pets for Duluth may be higher than the actual number of pets that are potential sources of *E. coli* to streams. No information was provided by the municipalities on the percent of pet waste that is picked up.

Table 33. Density of pets in *E. coli* impaired watersheds.

Impaired Segment	City or Township	Pets (#/square mile)	Number of Pets
Chester Creek	City of Duluth City of Rice Lake	44	297
Keene Creek	City of Duluth City of Hermantown	24	151
Merritt Creek	City of Duluth City of Hermantown	40	89
Miller Creek	City of Duluth City of Hermantown City of Rice Lake	34	330
Sargent Creek	City of Duluth Midway Township City of Proctor	35	108
Stewart Creek	City of Duluth Midway Township City of Proctor	34	58
Tischer Creek	City of Duluth City of Rice Lake	31	233

Wildlife

Wildlife contribute to *E. coli* loading in the watersheds. The DNR Wildlife office in Duluth provided a general review of wildlife in the *E. coli* impaired streams. Although surveys are not conducted in the Duluth area, the following observations were provided:

- All subwatersheds of *E. coli* impaired streams have populations of white-tailed deer and most have resident black bears.
- All subwatersheds have populations of mink, most likely have raccoons, red and gray foxes, cottontail rabbits, gray squirrels, chipmunks, smaller weasels, and a variety of mice and voles. Some of the reaches also likely have river otters.
- Seasonally large populations of Canada geese, ring-billed gulls, and a variety of waterfowl occur at the mouths of Miller, Merritt, Keene, Kingsbury, and Stewart creeks.
- Some of the more suburban or rural reaches may have populations of coyotes, bobcats, and occasionally gray wolves.

The U.S. Fish and Wildlife office was also contacted for further information on wildlife populations within the project area, however no further information was received. No further information was provided by the watershed municipalities, with the exception of Proctor that reported only a few deer within their community.

Additional literature information on urban wildlife sources of *E. coli* to streams was compiled to better understand the potential impact of urban wildlife to impaired streams. Waste from raccoons, rats, and birds may contribute a significant portion of *E. coli* to impaired streams in urban portions of the watershed. While raccoons do not typically live in stormsewers, they often use the sewers to navigate the city, hide, and defecate. A study in Boulder, Colorado found areas with large deposits of raccoon waste at junctions within the stormsewer system that were contributing to bacteria levels at the outlet (City of Boulder 2013). Impacts from urban wildlife may also be seasonal. Ram et al. (2007) detected raccoons as a source of *E. coli* to the Huron River in Michigan in the late summer and fall, while domestic pet fecal indicator bacteria levels were a prominent source of *E. coli* in stormsewers during the spring and summer (Urban Water Resources Research Council 2014). Geldreich (1976) reported that large populations of rodents may also contribute significant amounts of fecal material in urban areas.

Livestock

The MPCA Data Desk provided the feedlot locations, numbers of animals, and types of animals in registered feedlots. One registered feedlot in the *E. coli* impaired watersheds was identified in the Tischer Creek Watershed and is registered for two swine (less than one animal unit). The feedlot is located over 3.5 miles upstream of the impaired stream reach.

The location and number of animals at a site determines whether or not a feedlot must register. Livestock in smaller operations that are not required to be registered (e.g., hobby farms) may also contribute *E. coli* to surface waters through watershed runoff from fields and direct deposition in surface waters. Information from St. Louis County on non-registered livestock operations within St. Louis County shows no non-registered feedlots in the *E. coli* impaired watersheds. The City of Duluth issues permits within their city limits for various livestock (e.g., horses), however, no further information was provided.

3.5.4 Longitudinal Analysis of Water Quality Data

E. coli data were evaluated to determine if pollutant loading “hot spots” could be identified based on longitudinal patterns in concentration. In general, *E. coli* data are limited for this type of analysis, and, with the exception of Miller Creek, are available from only one or two monitoring sites on each impaired reach. Longitudinal patterns in *E. coli* concentrations are not evident in the analyses. An effort was also made to determine if correlations existed between concentrations and rain events. Higher concentrations tended to follow rainfall events, however results were not conclusive.

The location of monitoring stations is also relevant to understanding the water quality data (Table 34; see figures for each creek below). Monitoring stations on Sargent and Stewart creeks are both located very near the outlet, therefore monitoring data collected on those streams is representative of the entire watershed. All other watersheds have much higher density of urban development downstream of the monitoring station than above, therefore the full extent of developed land area is not represented in the monitoring data.

Table 34. Density of developed land above and below monitoring station

	Total area in watershed (acres)	Area upstream of monitoring station (acres)	Density of developed land above and below monitoring station (above/below in %)
Chester Creek	4,315	3,823	25/59
Keene Creek	4,029	3,794	22/88
Merritt Creek	1,412	1,152	29/65
Miller Creek	6,212	4,016	38/58
Tischer Creek	4,767	4,508	33/84

Chester Creek

E. coli results are available for two monitoring sites along Chester Creek: S004-953 and S008-481 (Figure 45, Figure 46). These two sites are located approximately 300 feet from one another; a parking lot and road drain to the creek at the downstream station. Because the data were collected from different time periods, longitudinal patterns cannot be assessed.

E. coli concentrations at sites (S004-953 and S008-481) on Chester Creek were also evaluated with daily precipitation records from the Duluth International Airport. Results for site S004-953 are presented in Figure 47 and Figure 48, while Figure 49 presents the results for site S008-481.

Elevated *E. coli* concentrations were detected at both sites on days with or immediately following a precipitation event. Additionally, several sets of samples were collected at site S008-481 after a precipitation event, and show decreasing *E. coli* levels on the second consecutive day of sampling; see June 15–16, 2016, and July 11–12, 2016 (Figure 49).

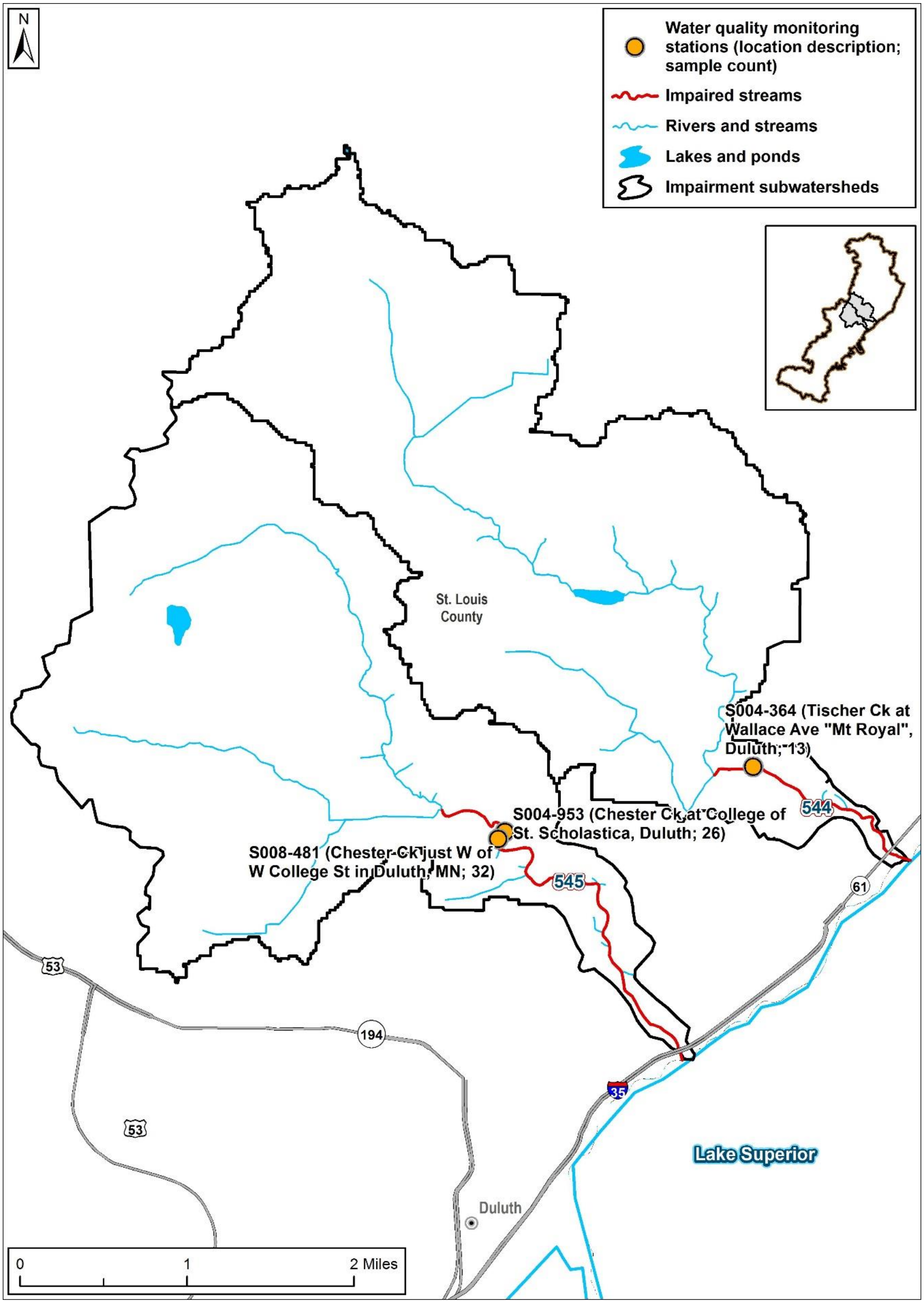


Figure 45. ***E. coli*** **monitoring sites in the Chester Creek and Tischer Creek watersheds.**

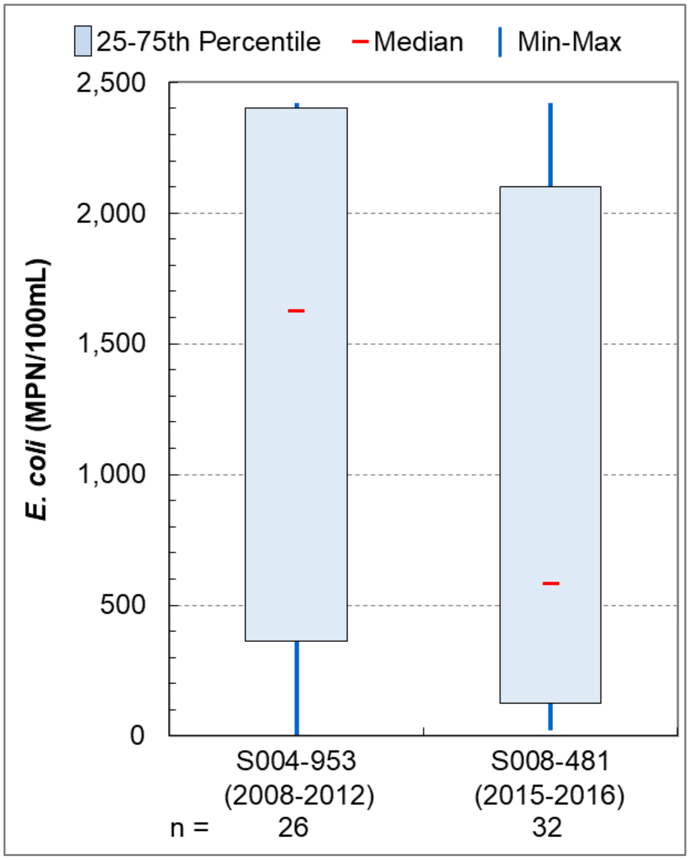


Figure 46. Summary of *E. coli* results at two sites on Chester Creek.

Only data collected between April 1 and October 30 in the specified years are presented in this figure.

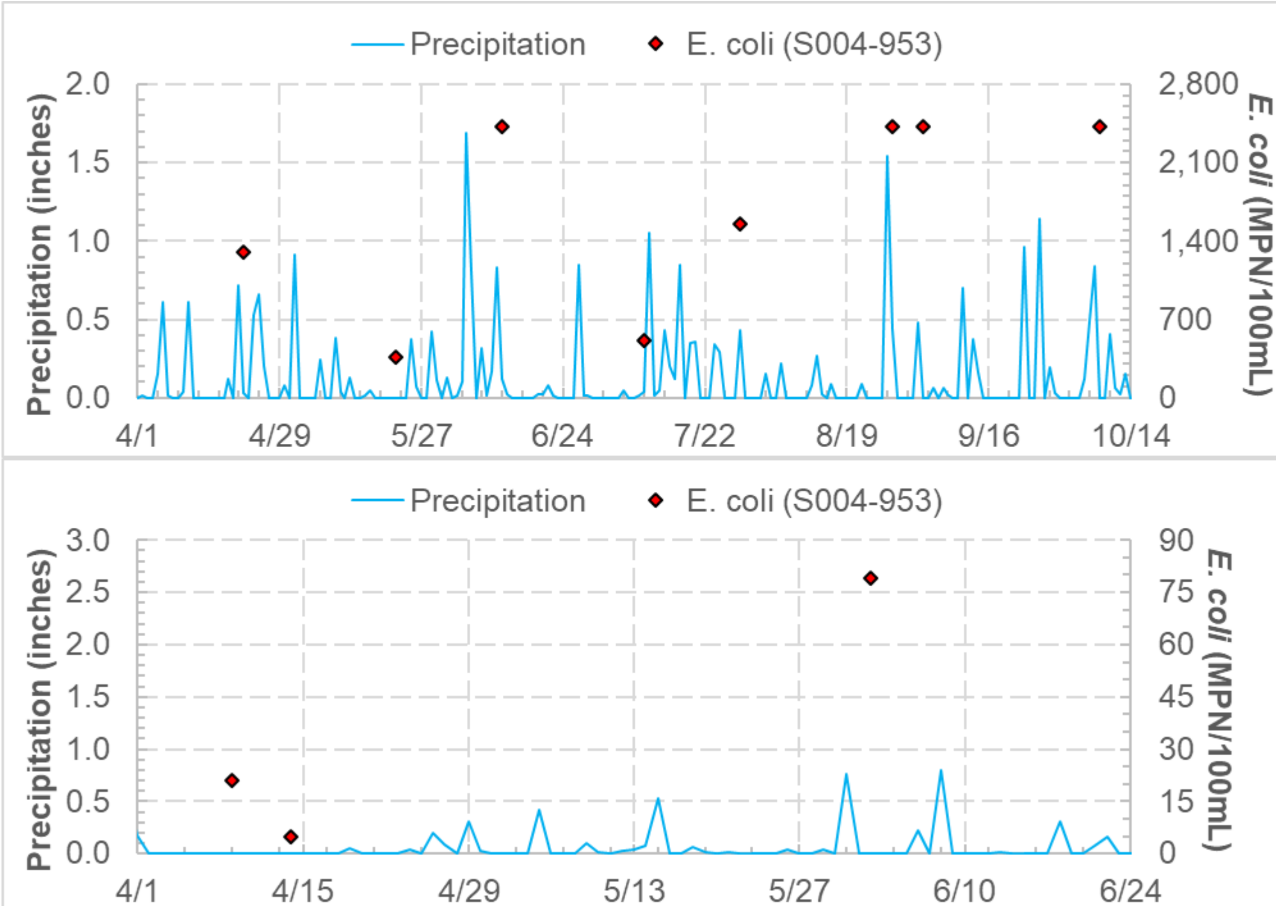


Figure 47. Precipitation at the Duluth International Airport and *E. coli* levels at monitoring site S004-953 on Chester Creek in 2008 (top) and 2009 (bottom).

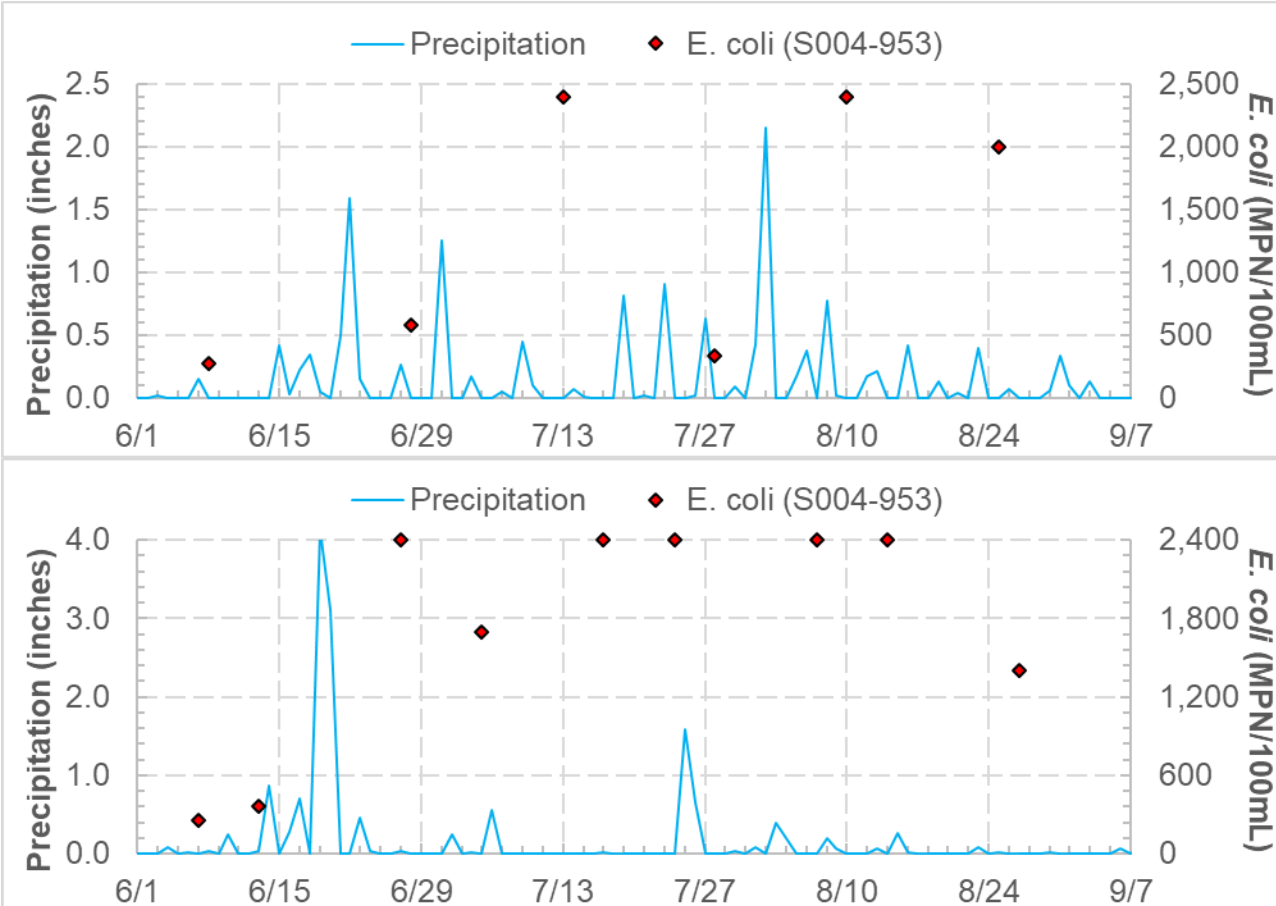


Figure 48. Precipitation at the Duluth International Airport and *E. coli* levels at monitoring site S004-953 on Chester Creek in 2011 (top) and 2012 (bottom).

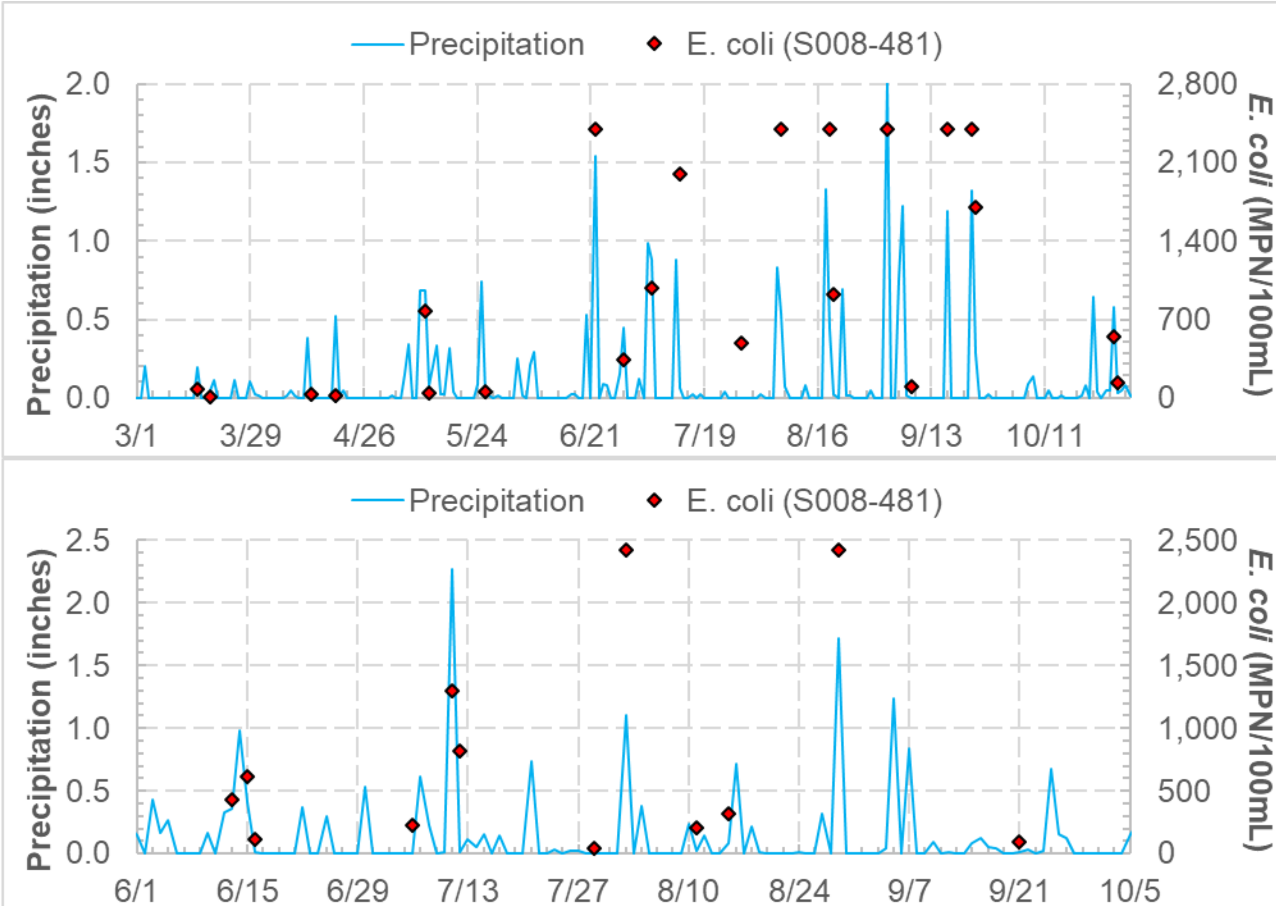


Figure 49. Precipitation at the Duluth International Airport and *E. coli* levels at monitoring site S008-481 on Chester Creek in 2015 (top) and 2016 (bottom).

Tischer Creek

E. coli results are available for one monitoring site along Tischer Creek - Tischer Creek at Wallace Ave "Mt Royal" (S004-364; Figure 45). Therefore, an evaluation of longitudinal patterns was not possible. *E. coli* results were also evaluated with daily precipitation records for three pairs of years: 2008–2009 (Figure 50), 2011–2012 (Figure 51), and 2015–2016 (Figure 52). Generally, *E. coli* concentrations increase considerably on dates during or immediately following precipitation. In a few cases, an elevated concentration was detected during a dry weather period (e.g., August 26, 2012 in Figure 51).

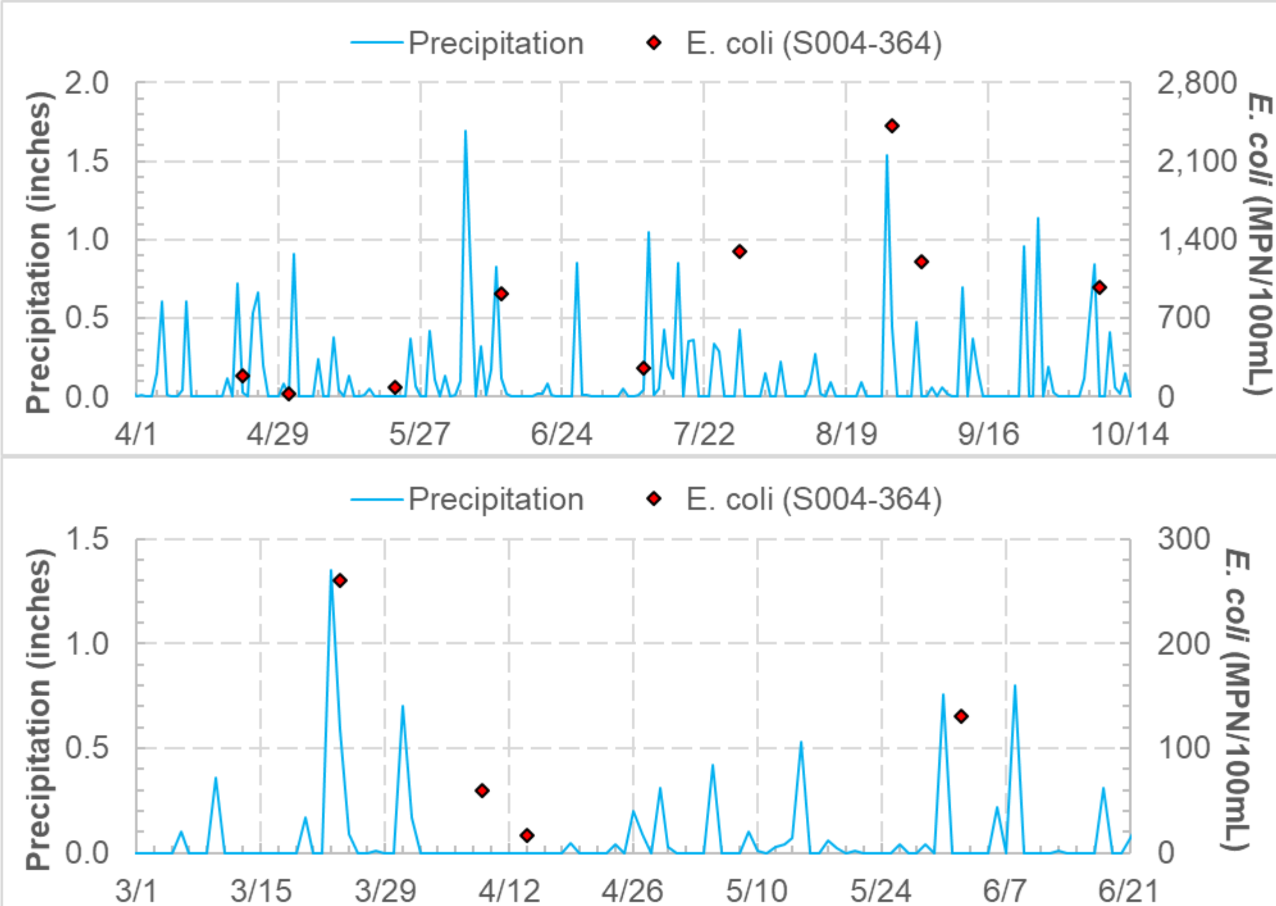


Figure 50. Precipitation at the Duluth International Airport and *E. coli* levels at monitoring site S004-364 on Tischer Creek in 2008 (top) and 2009 (bottom).

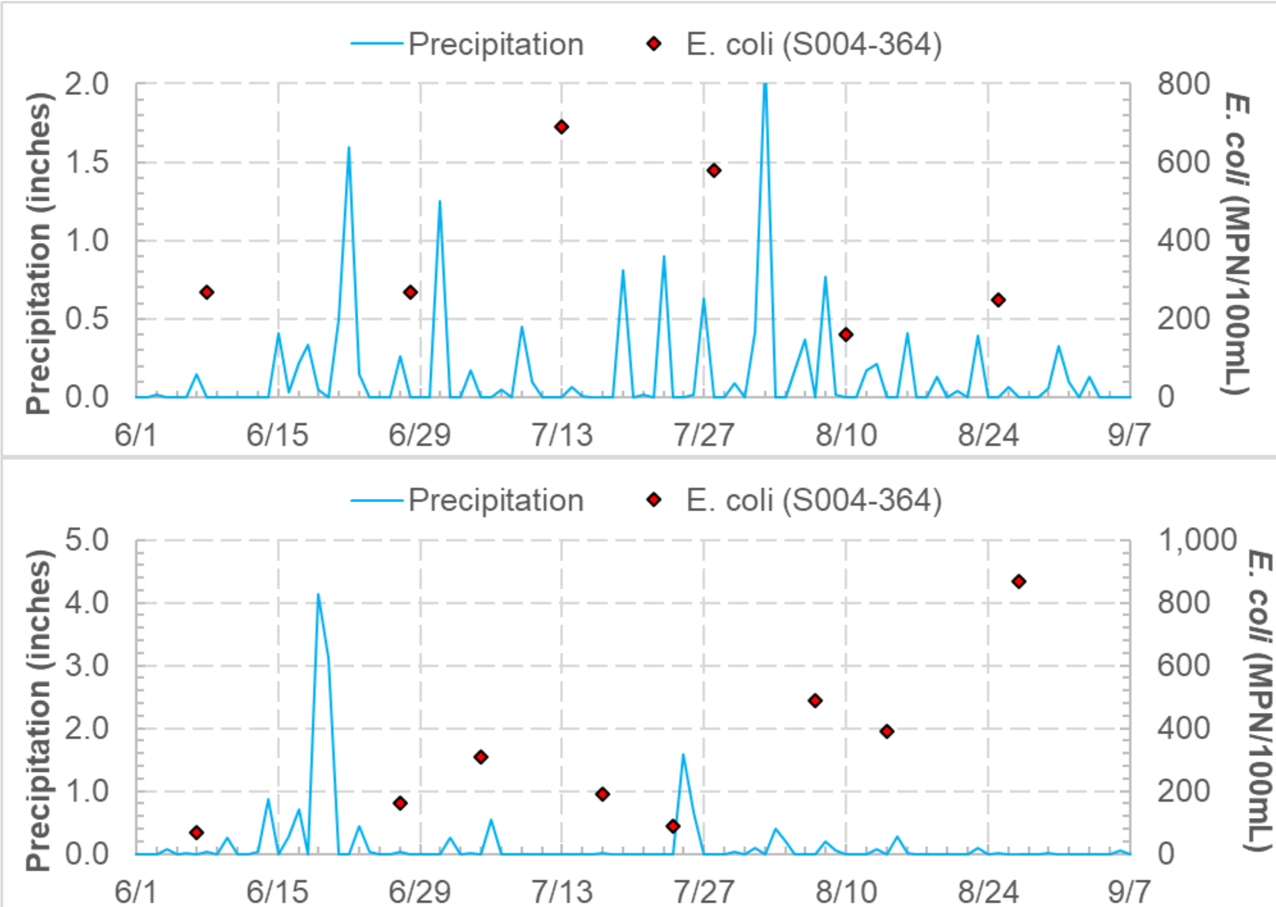


Figure 51. Precipitation at the Duluth International Airport and *E. coli* levels at monitoring site S004-364 on Tischer Creek in 2011 (top) and 2012 (bottom).

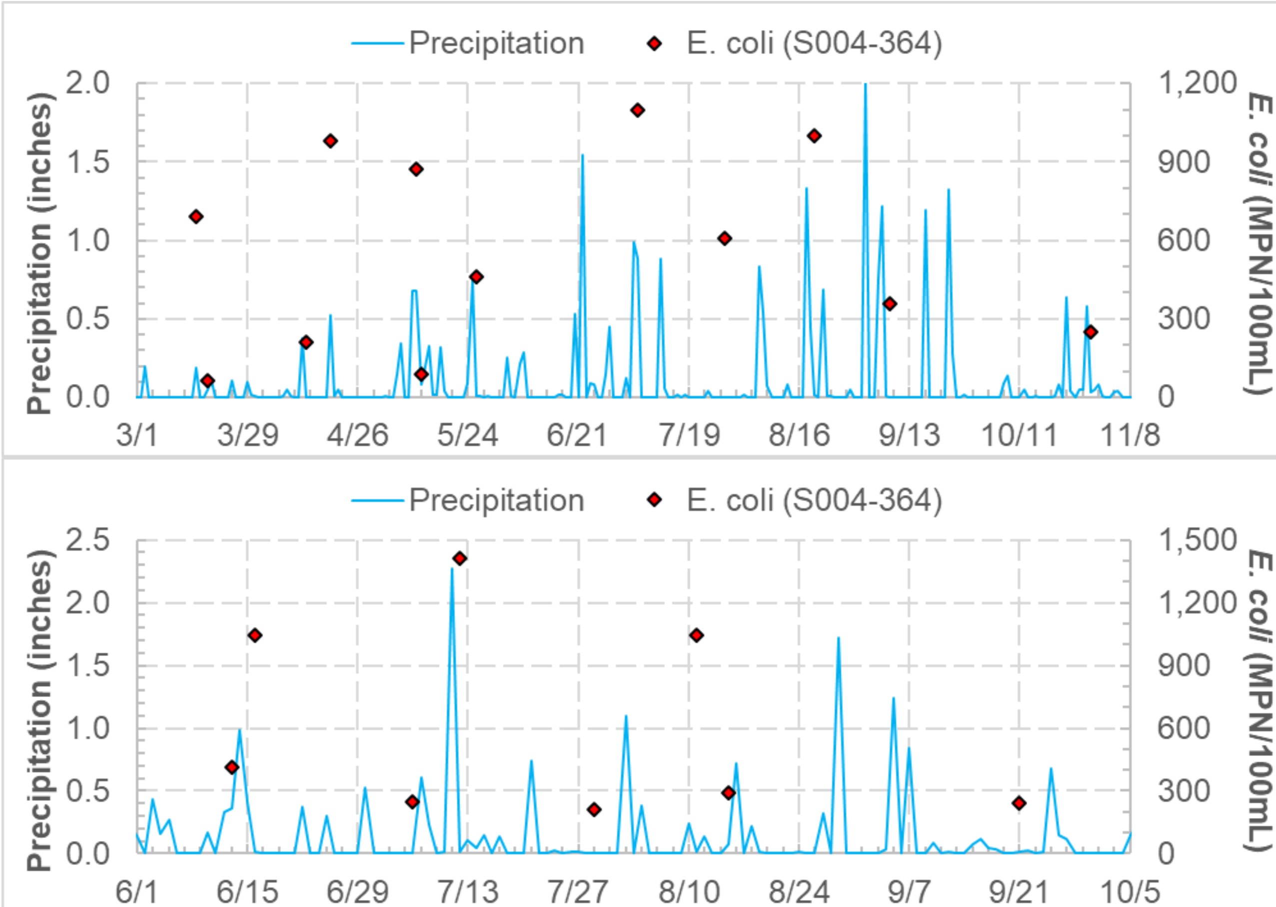
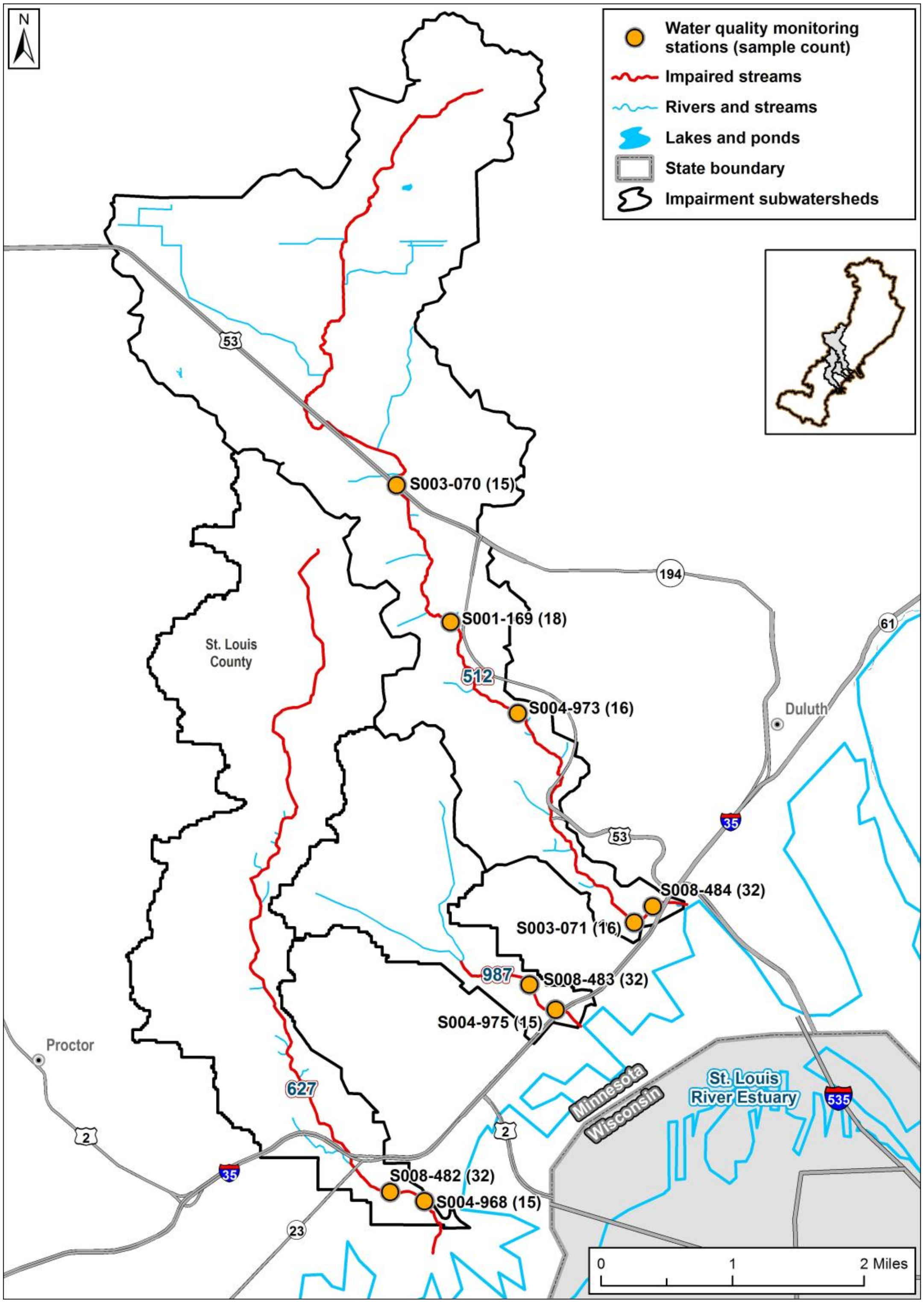


Figure 52. Precipitation at the Duluth International Airport and *E. coli* levels at monitoring site S004-364 on Tischer Creek in 2015 (top) and 2016 (bottom).

Unnamed Creek (Merritt Creek)

E. coli results are available for two monitoring sites on Merritt Creek, which are located approximately one-third mile from one another (Figure 53). Because the data were collected from different time periods (Figure 54), longitudinal patterns cannot be assessed. *E. coli* results at site S004-483 were evaluated with daily precipitation records (Figure 55). Similar to other water bodies in the Duluth area, *E. coli* concentrations increase considerably on dates during or immediately following precipitation.



- S003-070: Miller Cr, upper gage site at Hwy 53
- S001-169: Miller Cr at Chambersburg Rd T50N
- S004-973: Miller Cr at Lk Superior College
- S003-071: Miller Ck, lower site at 26th Ave W
- S008-484: Miller Ck just E of N 24th Ave W
- S008-483: Unn str (Merritt Creek) at Grand Ave
- S004-975: Unn str at W Superior St
- S008-482: Keene Ck at 57th Ave W
- S004-968: Keene Cr at Raleigh St

Figure 53. *E. coli* monitoring sites in Merritt Creek, Miller Creek, and Keene Creek watersheds.

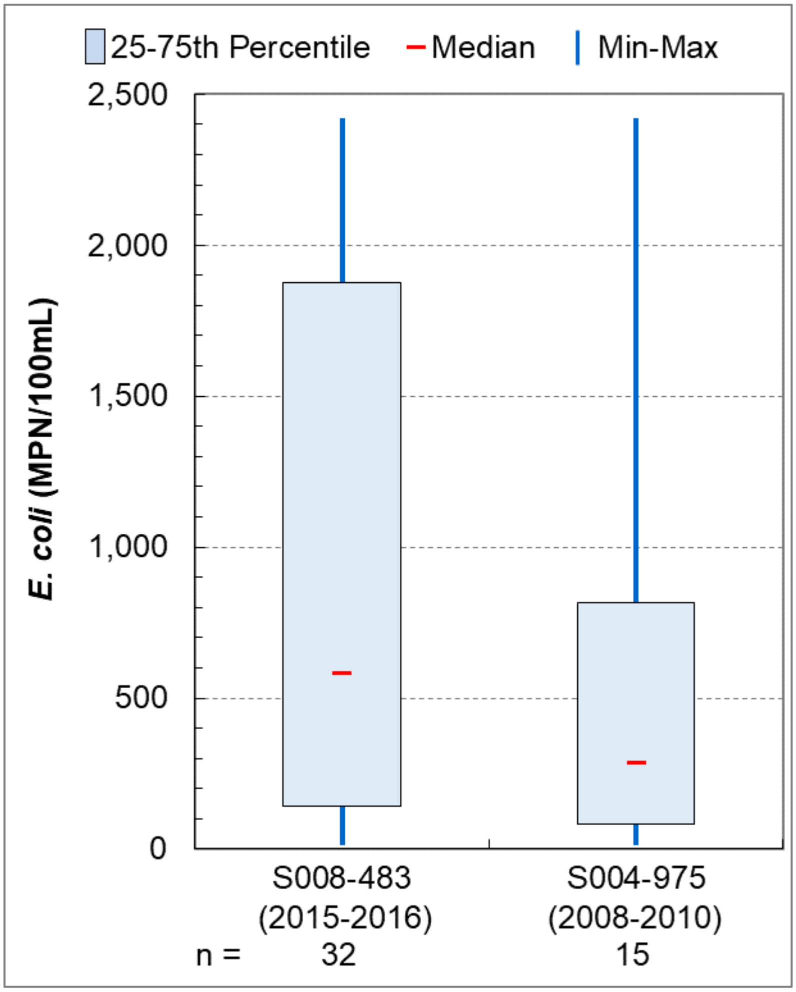


Figure 54. Summary of *E. coli* results at two sites on Merritt Creek.
Only data collected between April 1 and October 30 in the specified years are presented in this figure.

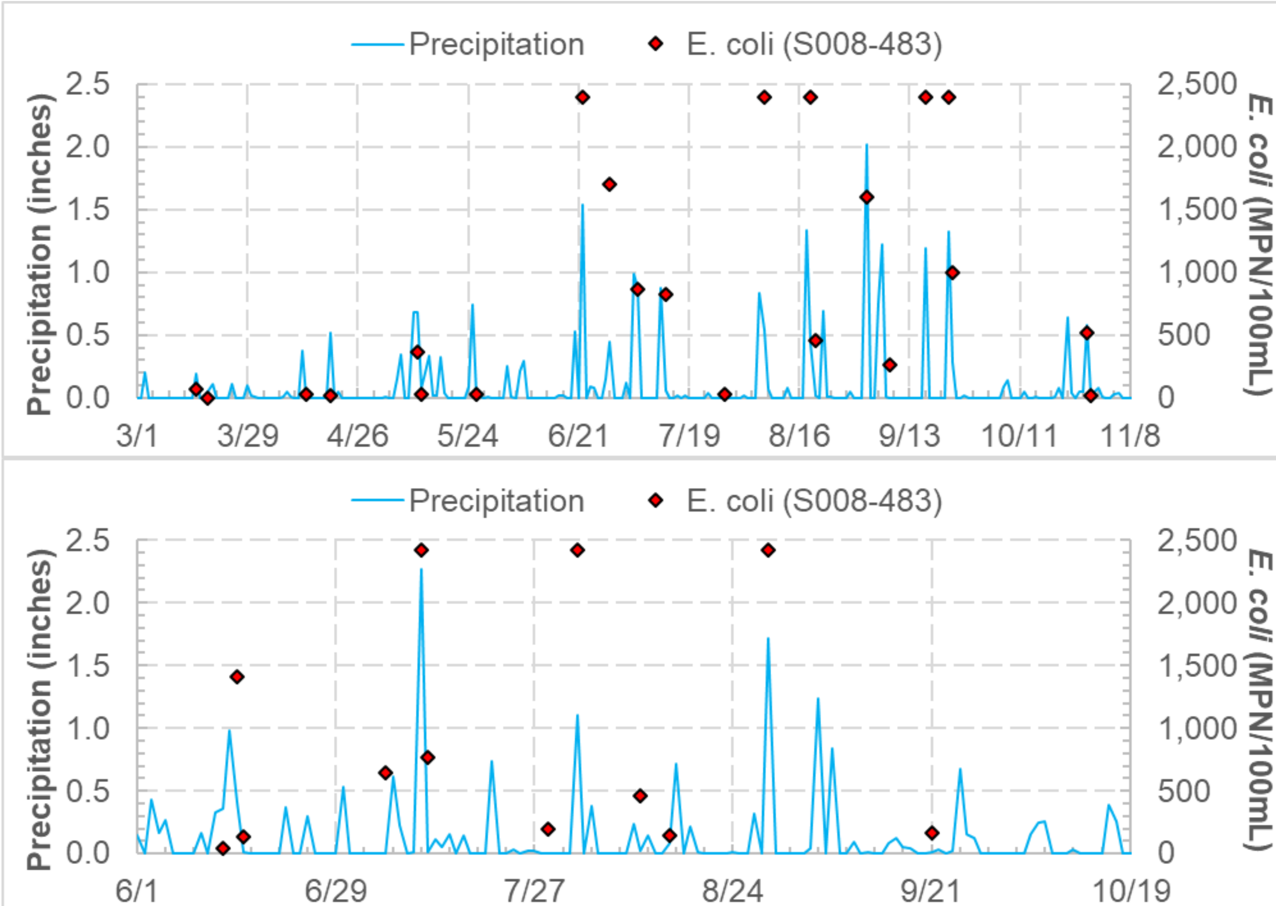


Figure 55. Precipitation at the Duluth International Airport and *E. coli* levels at monitoring site S004-483 on Merritt Creek in 2015 (top) and 2016 (bottom).

Stewart Creek

E. coli results are available for one monitoring site on Stewart Creek (Figure 56); therefore, an evaluation of longitudinal patterns was not possible. Results were also evaluated with daily precipitation data from the Duluth International Airport (Figure 57). Elevated concentrations in 2009 and 2010 typically occurred during or after precipitation events.

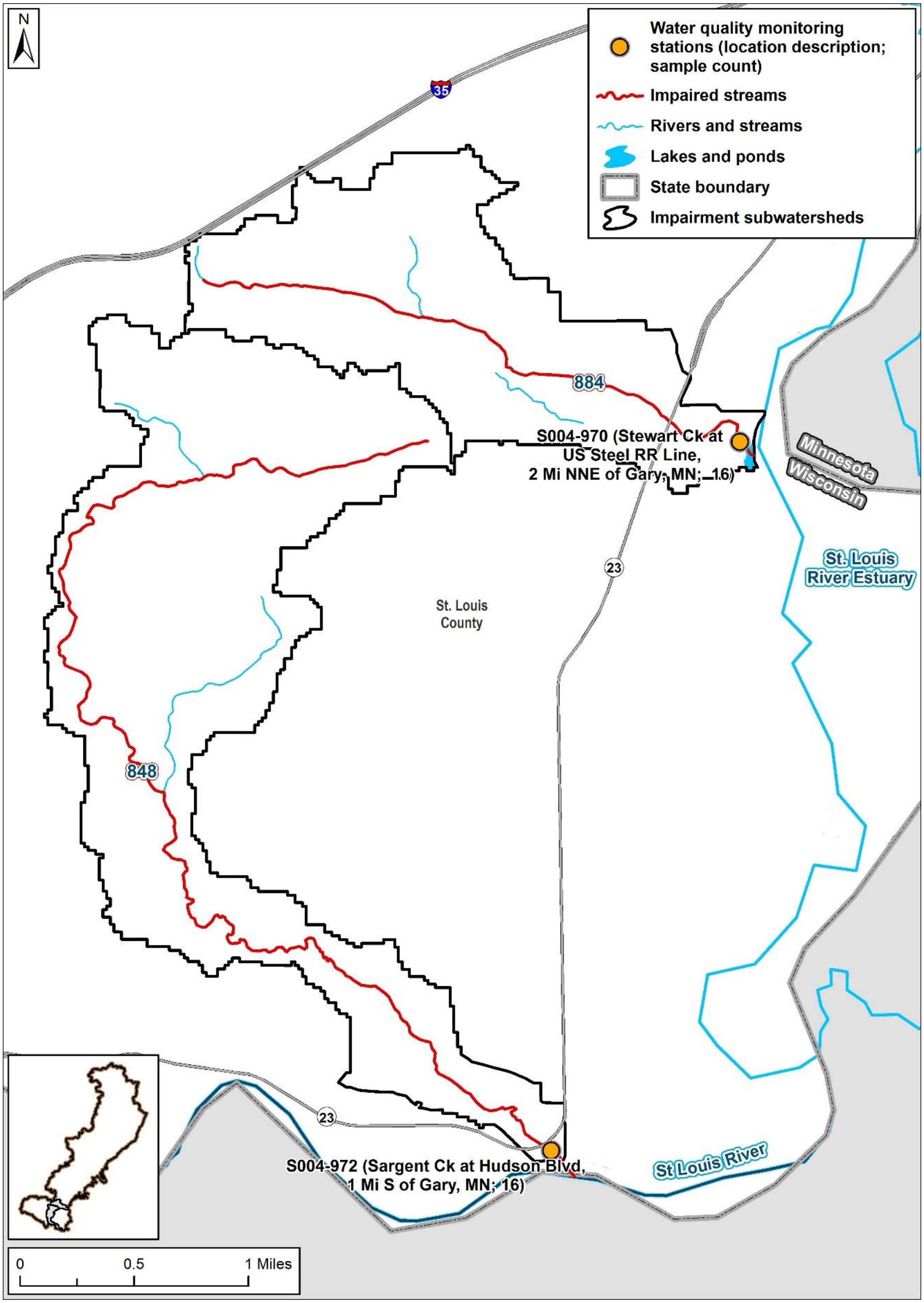


Figure 56. *E. coli* monitoring sites in Stewart Creek and Sargent Creek watersheds.

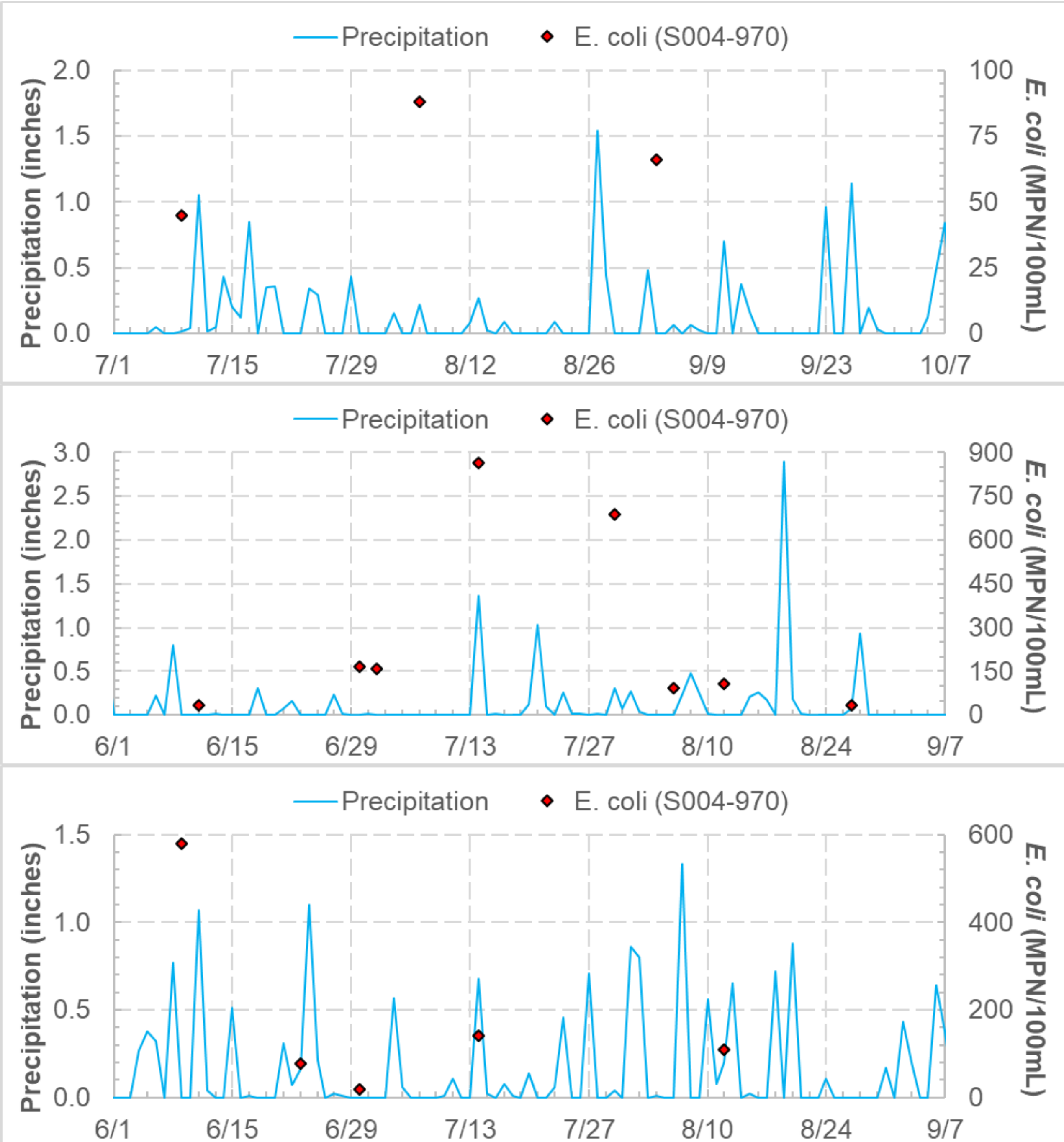


Figure 57. Precipitation at the Duluth International Airport and *E. coli* levels at monitoring site S004-970 on Stewart Creek in 2008 (top), 2009 (middle), and 2010 (bottom).

Sargent Creek

E. coli results are available for one monitoring site on Sargent Creek (Figure 56); therefore, an evaluation of longitudinal patterns was not possible. Results were also evaluated with daily precipitation data from the Duluth International Airport (Figure 58). Elevated *E. coli* concentrations typically occurred during or after precipitation events.

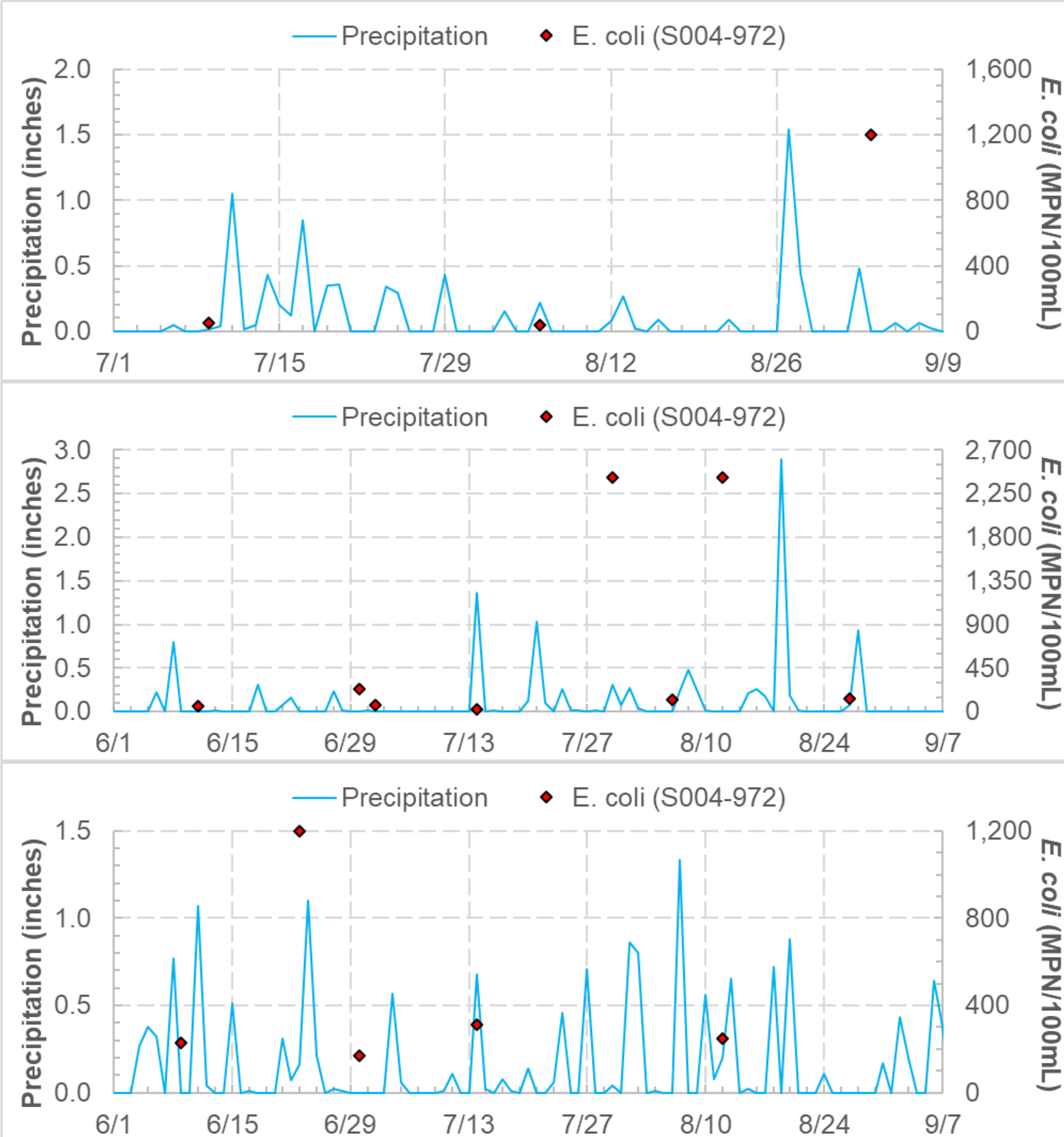


Figure 58. Precipitation at the Duluth International Airport and *E. coli* levels at monitoring site S004-970 on Sargent Creek in 2008 (top), 2009 (middle), and 2010 (bottom).

Miller Creek

E. coli results are available for five monitoring sites along Miller Creek (Figure 53). Four sites were sampled in 2008 through 2010 and one site was sampled in 2015 and 2016 (Figure 59). In 2008, concentrations on average were higher towards the downstream portion of the creek, at site S003-071. However, this pattern was not observed in 2009 or 2010. Samples were typically not taken on the same day at the multiple sites, and therefore conclusions regarding longitudinal patterns should be considered preliminary.

E. coli concentrations at the most downstream site, S008-484, were generally higher than at the other sites; however, these data are from a different time period (2015 through 2016) and therefore cannot be compared directly.

E. coli results on Miller Creek were also evaluated with daily precipitation records from the Duluth International Airport. Results for four sites sampled in 2008 through 2010 are presented in Figure 60, and results for site S004-484 for 2015 and 2016 are presented in Figure 61. Similar to other water bodies in the Duluth area, elevated *E. coli* concentrations were detected at all five sites on days with or immediately following a precipitation event.

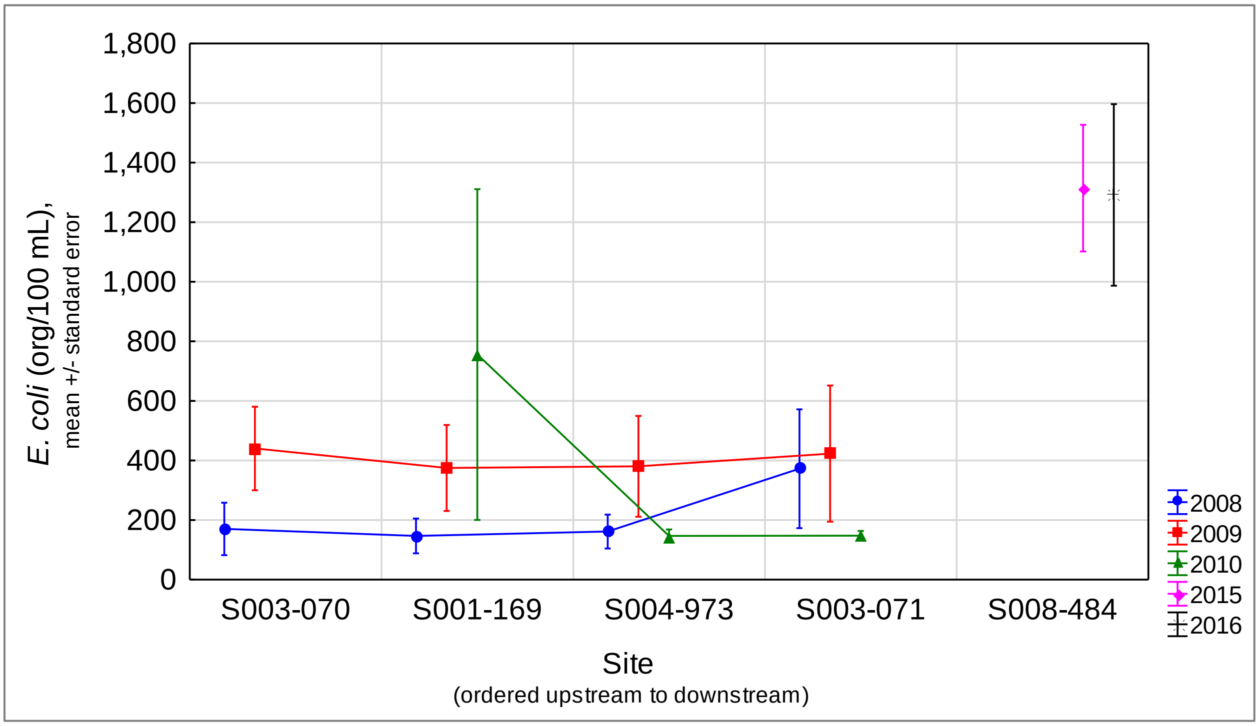


Figure 59. Summary of *E. coli* results at five sites on Miller Creek.
Only data collected between April 1 and October 30 in the specified years are presented in this figure. See Figure 53 for monitoring site names.

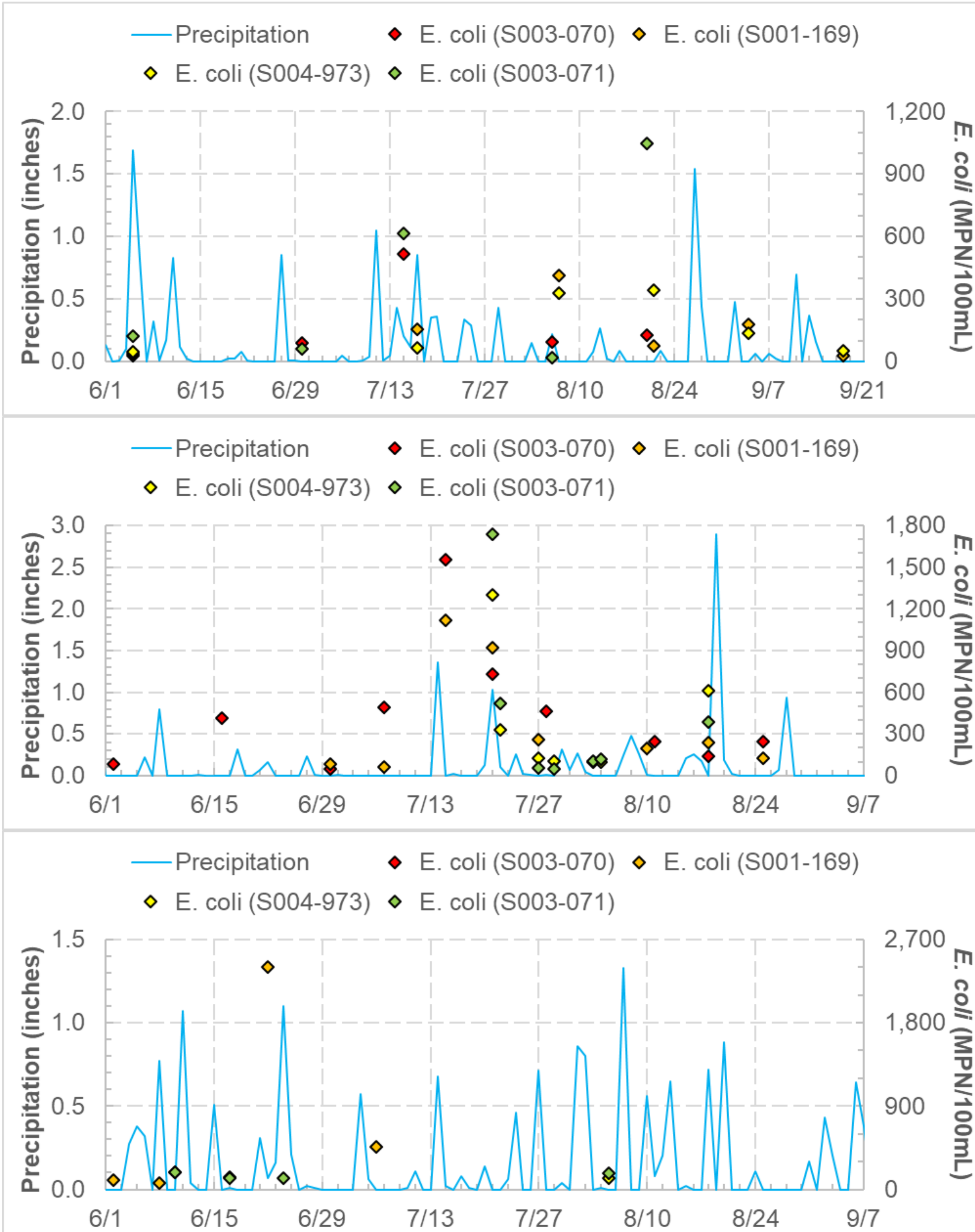


Figure 60. Precipitation at the Duluth International Airport and *E. coli* levels at monitoring sites S003-370, S001-169, S004-973, and S003-071 on Miller Creek in 2008 (top), 2009 (middle), and 2010 (bottom).

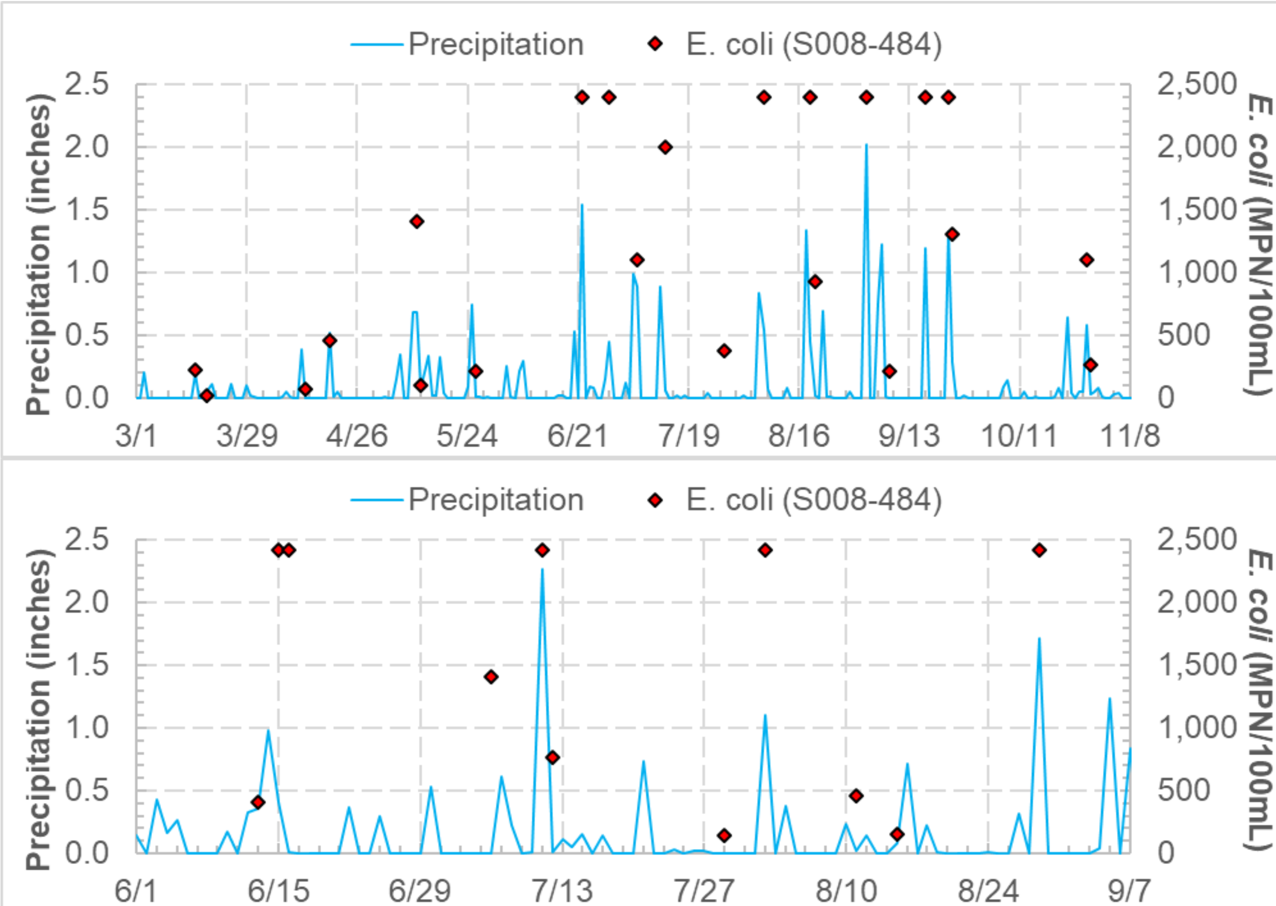


Figure 61. Precipitation at the Duluth International Airport and *E. coli* levels at monitoring site S008-484 on Miller Creek in 2015 (top) and 2016 (bottom).

Keene Creek

E. coli results are available for two monitoring sites along Keene Creek; both sites are located towards the bottom of the impaired reach, and the sites are located less than one-third mile from one other: S004-468 and S008-482 (Figure 53). Because the data were collected from different time periods (Figure 62), longitudinal patterns cannot be assessed.

E. coli results at site S008-482 were also evaluated with daily precipitation records (Figure 63). As with nearby streams, elevated *E. coli* concentrations were detected on days with or immediately following a precipitation event. About 40% of samples exceeded the maximum detection limit. These results occurred when several precipitation events occurred across several days in a short time period.

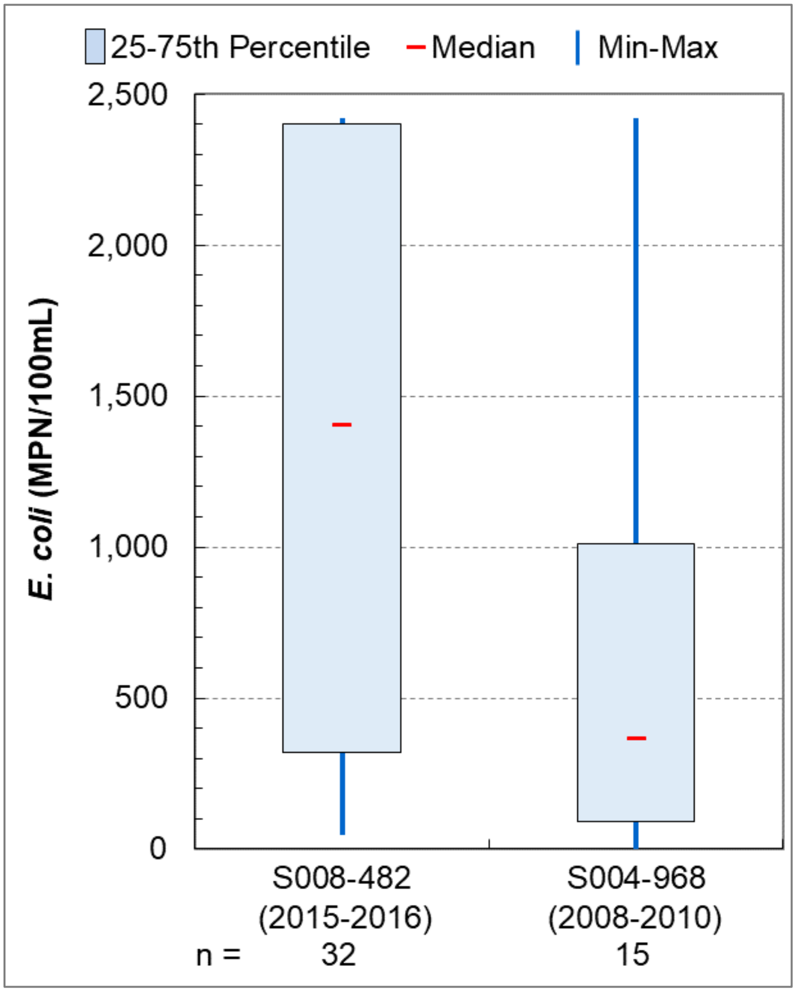


Figure 62. Summary of *E. coli* results at two sites on Keene Creek.

Only data collected between April 1 and October 30 in the specified years are presented in this figure. See Figure 53 for the monitoring site names.

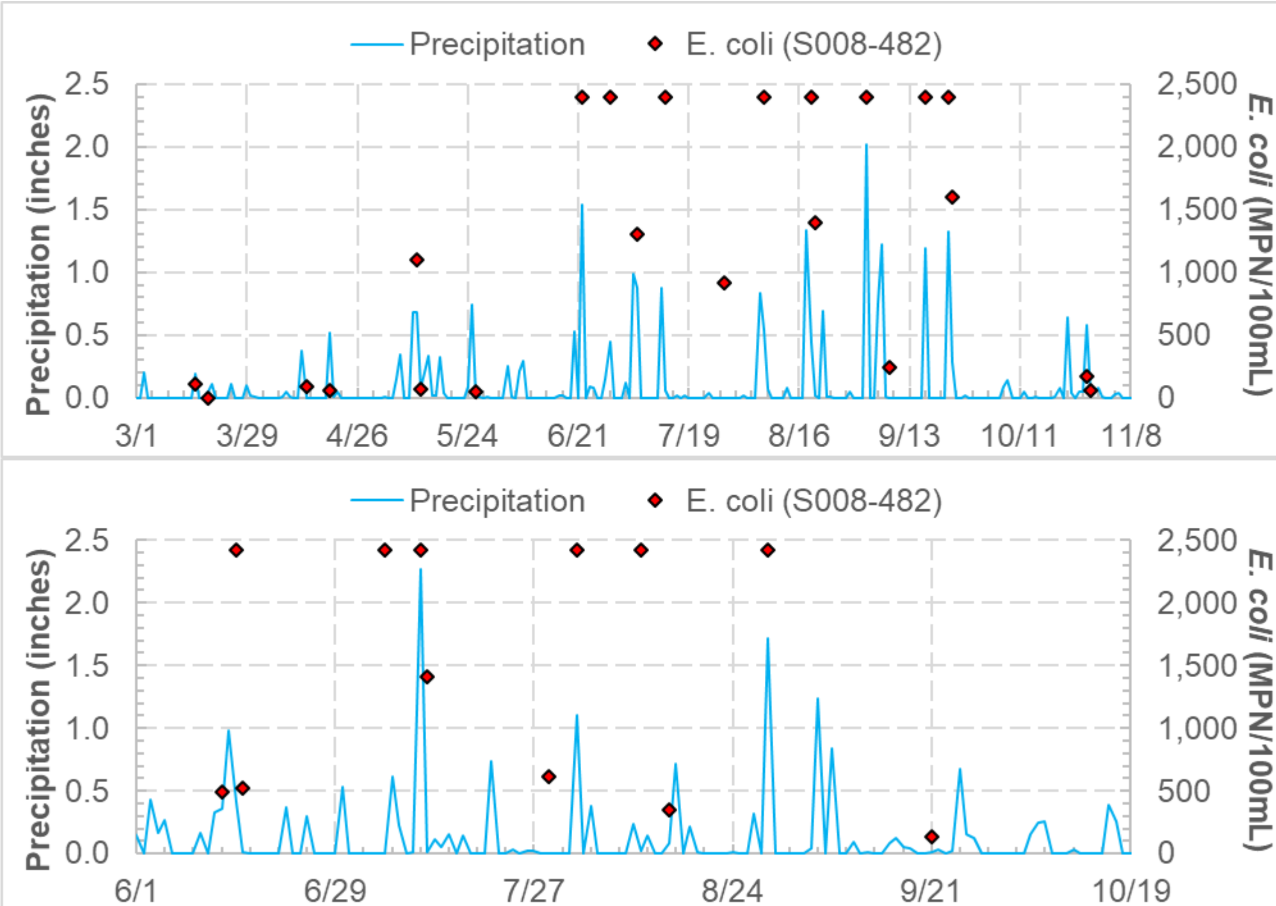


Figure 63. Precipitation at the Duluth International Airport and *E. coli* levels at monitoring site S008-482 on Keene Creek in 2015 (top) and 2016 (bottom).

3.5.5 *E. coli* Sources Summary

A summary of fecal bacteria sources is provided below:

- Chester Creek and Stewart Creek both have evidence of human fecal contamination based on DNA analysis.
- Evidence of gulls and ruminants were found in Chester Creek. Evidence of ruminants were found in Stewart Creek.
- Noncompliant and ITPHS septic systems are likely contributing to *E. coli* loading in most of the watersheds. Tischer Creek has the largest number of estimated septic systems.
- Pet waste is a likely contributor to *E. coli* loading in all of the streams, with the highest density of pets in the Chester Creek Watershed.
- Livestock in the watersheds may be contributing to *E. coli* loading, however the uncertainty will be high in estimating this proportion due to a lack of data.
- No new quantitative data were found for wildlife or sanitary sewers.

Monitoring data did not provide any additional data on hotspots or longitudinal trends.

4. TMDL Development

A TMDL is the total amount of a pollutant that a receiving water body can assimilate while still achieving water quality standards. TMDLs can be expressed in terms of mass per time or by other appropriate measures. TMDLs are composed of the sum of wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources and natural background levels. In addition, the TMDL includes a MOS, either implicit or explicit, that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving water body. Conceptually, this is defined by the equation:

TMDL = WLA + LA + MOS

A summary of the allowable loads for all impairment-related parameters in the Duluth Urban Area is presented in this section. The allocations for each of the various sources and parameters are shown in the tables throughout this section. The approach to develop allocations was determined through a stakeholder involvement process, focused primarily on the MS4 entities. Meetings were held throughout 2019 to gather input and recommendations from stakeholders. The approaches provided below are the result of this input.

Allowable pollutant loads in streams are determined through the use of load duration curves. A load duration curve is similar to a water quality duration curve except that loads rather than concentrations are plotted on the vertical axis. Discussions of load duration curves are presented in *An Approach for Using Load Duration Curves in the Development of TMDLs* (EPA 2007). The approach involves calculating the allowable loadings over the range of flow conditions expected to occur in the impaired stream by taking the following steps:

1. A flow duration curve for the stream is developed by generating a flow frequency table and plotting the data points to form a curve. The data reflect a range of natural occurrences from extremely high flows to extremely low flows. The flow data are year-round simulated daily average flows (1995 through 2015) from the Duluth Urban Area HSPF model application. The model report (Tetra Tech 2019; Appendix A) describes the framework and the data that were used to develop the model, and includes information on the calibration. Calibration years for the model are 1995 through 2016.
2. The flow curve is translated into a load duration curve by multiplying each flow value by the water quality standard/target for a contaminant (as a concentration), then multiplying by conversion factors to yield results in the proper unit. The resulting points are plotted to create a load duration curve.
3. Each water quality sample is converted to a load by multiplying the water quality sample concentration by the average daily flow on the day the sample was collected. Then, the individual loads are plotted as points on the load duration curve graph and can be compared to the water quality standard/target, or load duration curve.
4. Points plotting above the curve represent deviations from the water quality standard/target and the daily allowable load. Those plotting below the curve represent compliance with standards and the daily allowable load.

5. The area beneath the TMDL curve is interpreted as the loading capacity of the stream. The difference between this area and the area representing the current loading conditions is the load that must be reduced to meet water quality standards/targets.

The stream flows displayed on load duration curves may be grouped into various flow regimes. The flow regimes are typically divided into 10 groups, which can be further categorized into the following five hydrologic zones:

- Very high flow zone: stream flows that plot in the 0 to 10-percentile range, related to flood flows
- High flow zone: flows in the 10 to 40-percentile range, related to wet weather conditions
- Mid-range flow zone: flows in the 40 to 60-percentile range, median stream flow conditions
- Low flow zone: flows in the 60 to 90-percentile range, related to dry weather flows
- Very low flow zone: flows in the 90 to 100-percentile range, related to drought conditions

The duration curve approach helps to identify the issues surrounding the impairment and to roughly differentiate among sources. Exceedances at the right side of the graph occur during lower flow conditions, and may be derived from sources such as failing septic systems. Exceedances on the left side of the graph occur during higher flow events, and may be derived from sources such as runoff. The load duration curve approach helps select implementation practices that are most effective for reducing loads on the basis of flow regime.

Table 35 summarizes the general relationship between the five hydrologic zones and potentially contributing source areas (the table is not specific to an individual pollutant). For example, the table indicates that impacts from channel bank erosion is most pronounced during high flow zones because these are the periods during which stream velocities are high enough to cause erosion to occur.

Table 35. Relationship between duration curve zones and contributing pollutant sources.

Contributing source area	Duration Curve Zone				
	Very High	**High**	**Mid-range**	**Low**	**Very Low**
Stormwater: Impervious		H	H	H	
Stormwater: Upland	H	H	M		
Septic systems	M	M-H	H	H	H
Riparian areas		H	H	M	
Stormwater	H	H	M		
Bank erosion	H	M			

Note: Potential relative importance of source area to contribute pollutant loads under given hydrologic condition (H: High; M: Medium; L: Low).

The load duration curve method was used to develop the stream TMDLs. The approach is based on an analysis that encompasses the cumulative frequency of historic flow data over a specified period. Because this method uses a long-term record of daily flow volumes, virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL equation tables, only five points on the entire loading capacity curve are depicted—the midpoints of the designated flow zones (e.g., for the high flow zone [0 to 10-percentile], the TMDL was calculated at the 5th percentile). However, the entire curve represents the TMDL and is what is ultimately approved by the EPA.

Table 3 and Figure 64 summarize the TMDLs developed as part of this study.

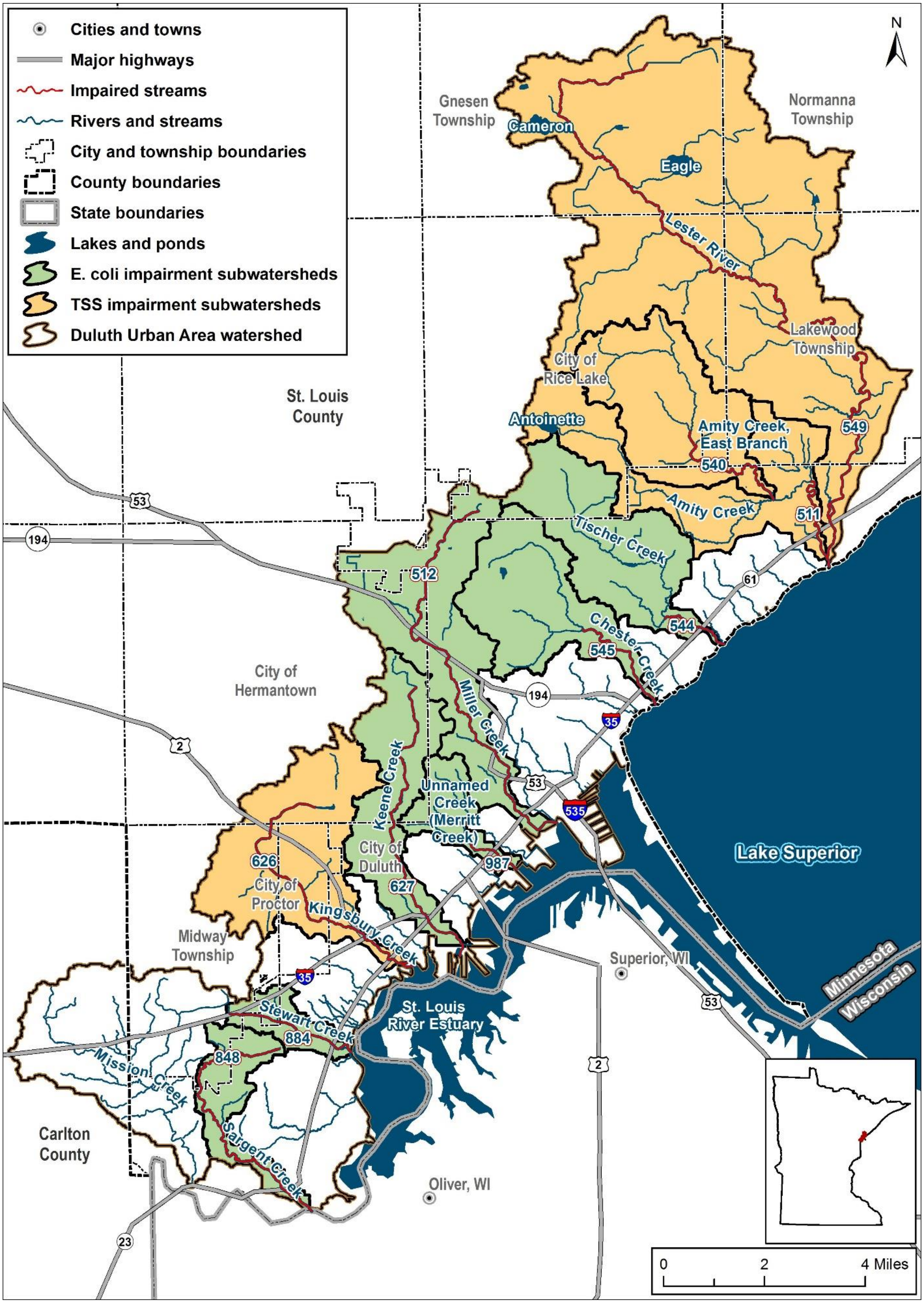


Figure 64. Impaired segments receiving TMDLs.

4.1 Total Suspended Solids

4.1.1 Approach

Loading Capacity

The loading capacity was calculated as flow multiplied by the TSS standard (10 mg/L), and represents the TSS load in the stream when the stream is at the TSS standard. The simulated flow data used to calculate the loading capacity needed to meet the TMDL are from 1995 through 2016. The loading capacities and allocations were rounded to two significant digits, except in the case of values greater than 100, which were rounded to the nearest whole number.

Load Reduction

Percent reductions for sediment-impaired segments are based on HSPF model simulations. The calibrated Duluth Urban Area HSPF model (Tetra Tech 2019) was used to evaluate sediment load reduction scenarios. The two largest sources contributing sediment to these impaired segments are developed lands and near-channel sources as described in Section 3.4.

A series of sediment reduction scenarios were implemented in HSPF to evaluate potential reductions from both of these sources. These reductions translate into reduced frequency of modeled exceedances during the months that the TSS water quality standard applies, April through September. Figure 65 and Figure 66 illustrate the results of the original baseline model (existing conditions) and two scenarios: 1) 50% reduction in sediment load from developed land covers and near-channel sources and 2) 60% reduction in sediment load from developed land covers and near-channel sources. Additional scenarios were run for the Lester River. The scenarios did not include reduction in peak flows or runoff volumes from the watershed.

Percent load reductions for each sediment-impaired water are derived from these modeling scenarios, and are based on achieving the water quality standard that allows exceedance of the concentration target (10 mg/L TSS) no more than 10% of the time between April 1 and September 30. The final TMDL scenarios include a 60% reduction for all developed land covers and near-channel sources in the four sediment-impaired watersheds, with a 90% reduction in the most downstream reach of Lester River. The far right image in Figure 65 (60% reduction scenario) illustrates the final TMDL scenario for Kingsbury Creek; Figure 67 illustrates the TMDL scenario for Amity Creek, East Branch Amity Creek and the Lester River. One tributary to Amity Creek shows exceedances of the water quality standard for more than 10% of the time; however, the impaired segment is downstream of this tributary and shows compliance with the standard. Therefore, no additional reductions are proposed for this tributary. The source attributions for the TMDL scenario are provided in Figure 68.

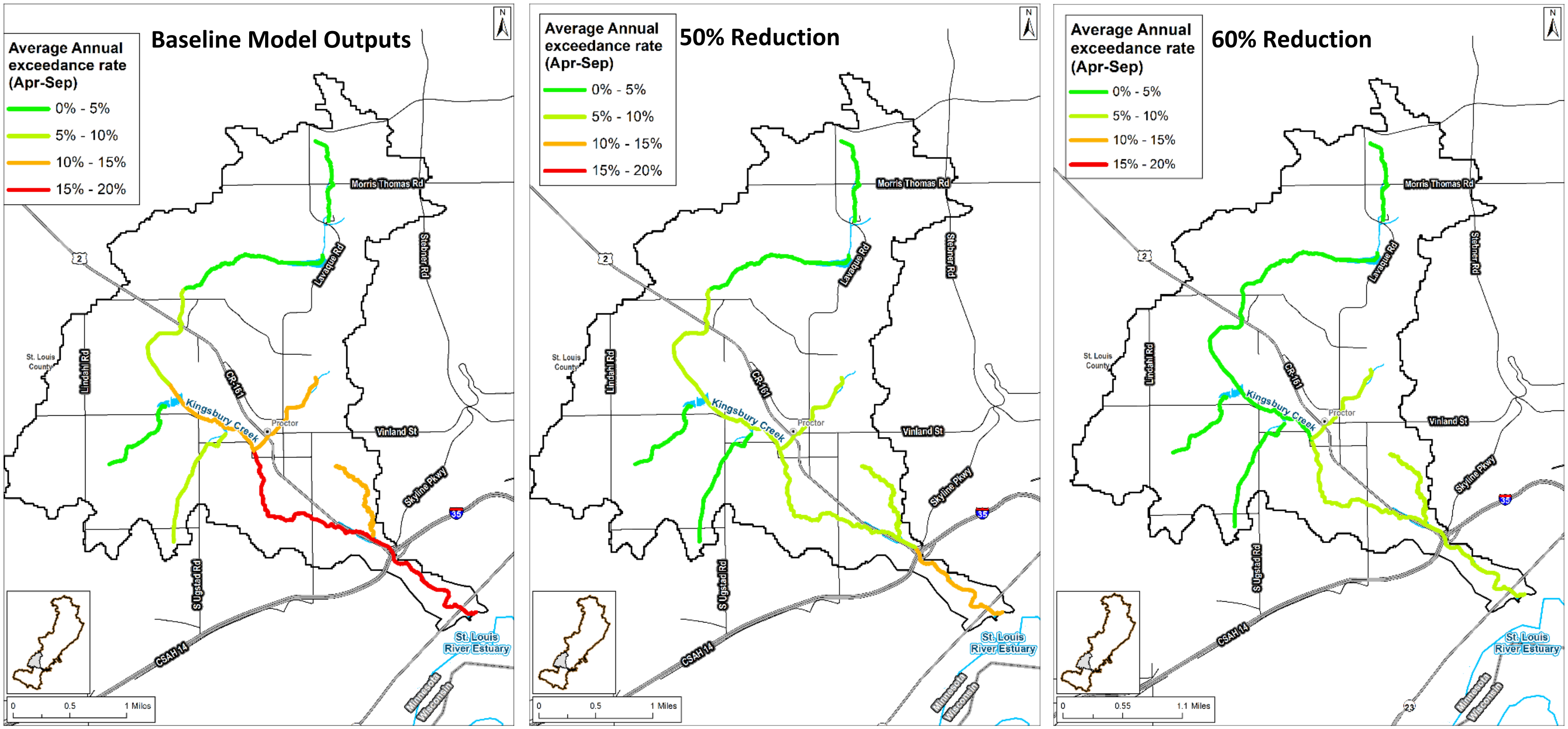


Figure 65. Kingsbury Creek - Percent of time TSS water quality standard is exceeded (April – September, 1995-2016).

Left: Baseline model outputs (existing conditions); Center: 50% reduction in TSS from developed land and near-channel sources; Right: 60% reduction in TSS from developed land and near-channel sources.

Green reaches have less than 10% exceedances of the TSS water quality standard based on the model output; orange and red segments have greater than 10% exceedances of the TSS water quality standard based on the model output. The goal is to achieve less than 10% exceedances in the impaired water.

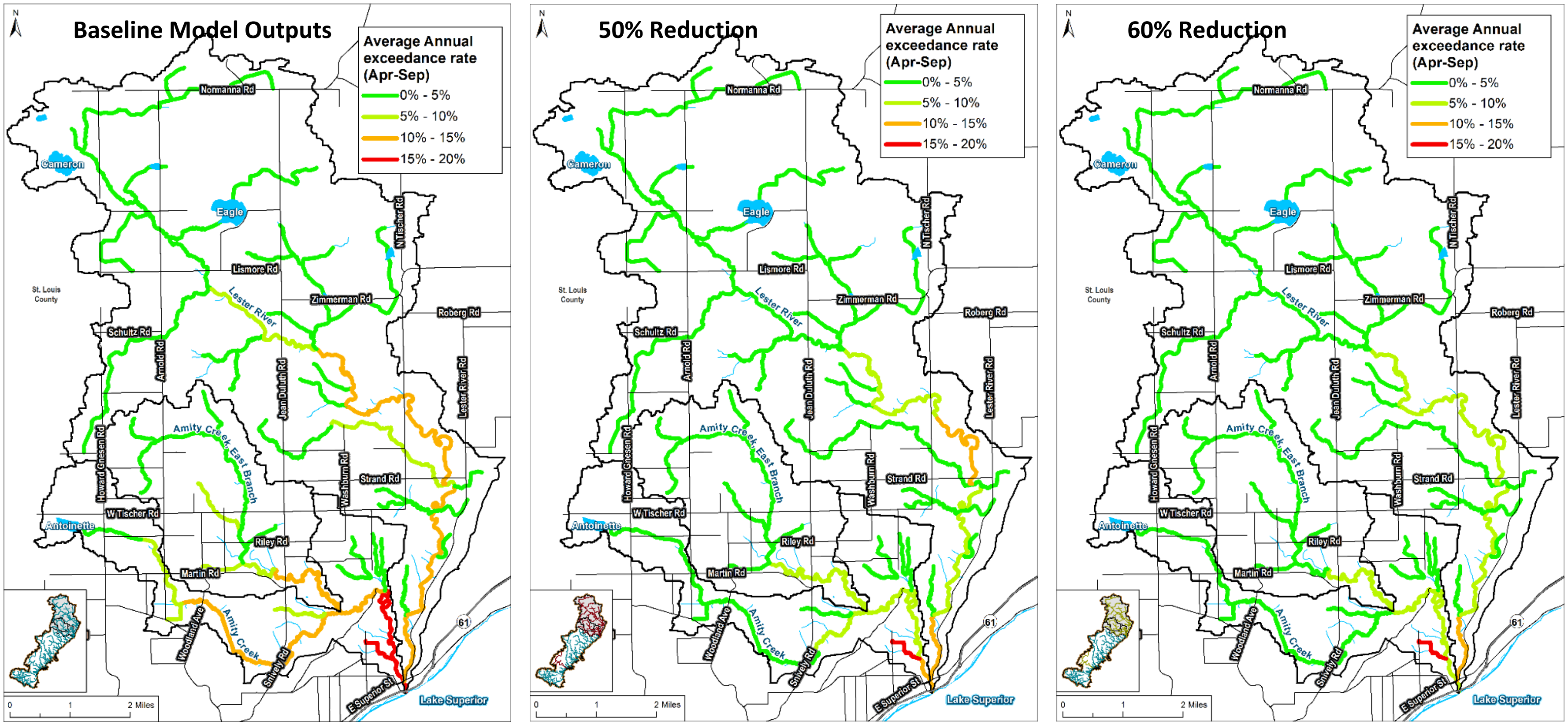


Figure 66. Amity Creek and Lester Creek - Percent of time TSS water quality standard is exceeded (April – September, 1995-2016).

Left: Baseline model outputs (existing conditions); Center: 50% reduction in TSS from developed land and near-channel sources; Right: 60% reduction in TSS from developed land and near-channel sources.

Green reaches have less than 10% exceedances of the TSS water quality standard based on the model output; orange and red segments have greater that 10% exceedances of the TSS water quality standard based on the model output. The goal is to achieve less than 10% exceedances in the impaired water.

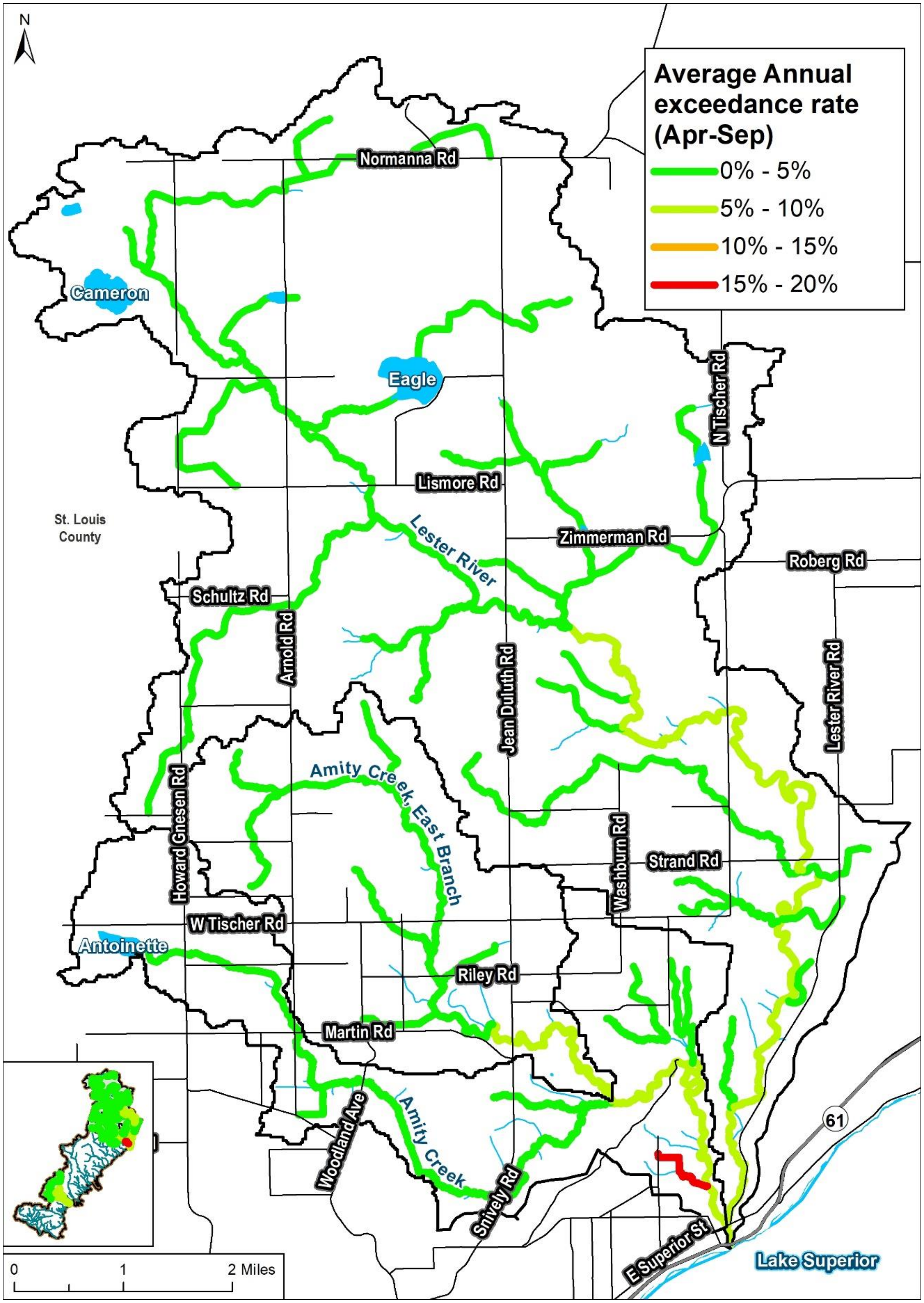


Figure 67. TMDL scenario results for Amity Creek and Lester River watersheds.

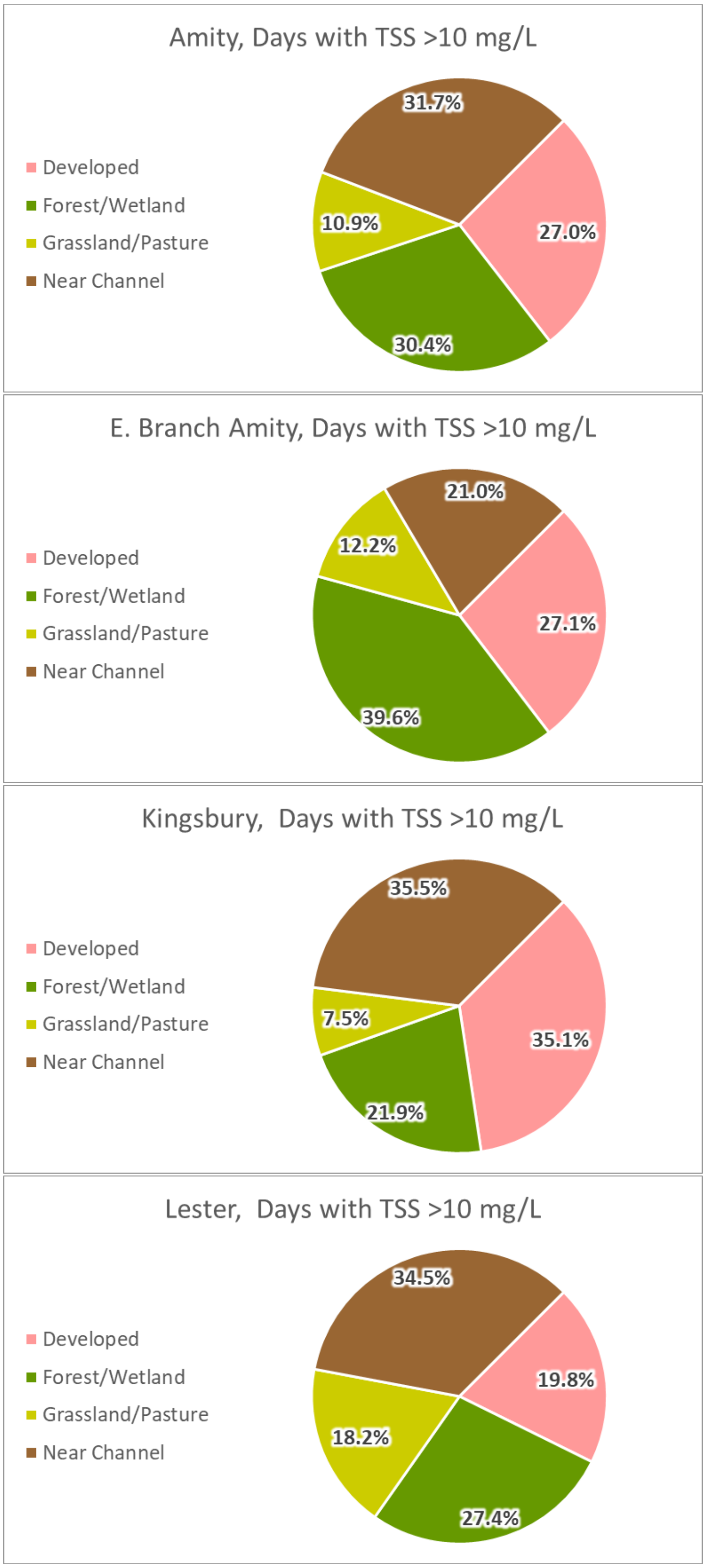


Figure 68. Sources of TSS when modeled under the TMDL scenario.

Baseline Year

The monitoring data used to support TMDL development are from 2007 through 2016. Because projects undertaken recently may take a few years to influence water quality, the baseline year for crediting load reductions for a given water body is 2011, the midpoint of the time period. Any activities implemented during or after the baseline year that led to a reduction in pollutant loads to the water bodies may be considered as progress towards meeting a WLA or LA.

Load Allocation

The LA represents the portion of the loading capacity that is allocated to unregulated pollutant loads (e.g., non-MS4 watershed runoff, near-channel erosion). The LA is split into near-channel sources and unregulated watershed runoff. The near-channel LA is calculated based on the percent of the load attributed to near-channel sources in the TMDL scenario as provided in Figure 68 as follows:

Near-channel LA *= (Loading capacity – MOS – industrial and construction stormwater WLA) x percent of load attributed to near-channel sources under the TMDL scenario*

The unregulated watershed runoff LA is calculated as follows:

Unregulated watershed runoff LA *= (Loading capacity – MOS – industrial and construction stormwater WLA – near-channel* LA*) x percent non-MS4 watershed area*

It should also be noted a percent reduction table is included with each TMDL load table that will identify non-MS4 developed and undeveloped area reduction needs. Within the watersheds, there are developed areas associated with non-MS4 communities of Gnesen, Normanna, Thomson and Lakewood townships.

The LA includes nonpoint pollution sources that are not subject to permit requirements and also includes natural background sources of sediment.

Natural background is defined in both Minnesota rule and statute:

Minn. R. 7050.0150, subp. 4:

> "Natural causes" means the multiplicity of factors that determine the physical, chemical or biological conditions that would exist in the absence of measurable impacts from human activity or influence.

The Clean Water Legacy Act (Minn. Stat. § 114D.10, subd. 10) defines *natural background* as:

> … characteristics of the water body resulting from the multiplicity of factors in nature, including climate and ecosystem dynamics that affect the physical, chemical or biological conditions in a water body, but does not include measurable and distinguishable pollution that is attributable to human activity or influence.

Natural background sources are inputs that would be expected under natural, undisturbed conditions. Natural background sources can include inputs from natural geologic processes such as: soil loss from upland erosion and stream development; atmospheric deposition; wildlife; and loading from grassland, forests, and other natural land covers. Based on the MPCA's water body assessment process and the TMDL source assessment exercises, there is no evidence at this time to suggest that natural background sources are a major driver of the water body impairments and/or affect their ability to meet state water quality standards. For all impairments addressed in this study, natural background sources are implicitly included in the LA portion of the TMDL, and TMDL reductions should focus on the major anthropogenic sources identified in the source assessment.

Additionally, the TSS standard inherently addresses natural background conditions. Minnesota's regional TSS standards are based on reference, or least-impacted, streams, and take into account differing levels of sediment present in streams and rivers in the many ecoregions across the state, depending on factors such as topography, soils, and climate (MPCA 2011). In developing the TSS standard, reference condition watersheds with minimal disturbance/development impacts were sources of the data that was collected, reviewed and incorporated into the standard.

Wasteload Allocation

The WLA represents the portion of the loading capacity that is allocated to pollutant loads that are regulated through an NPDES/SDS permit. Regulated stormwater sources (i.e., MS4s, construction stormwater, and industrial stormwater) are included in WLAs for TSS TMDLs. Stormwater runoff that is regulated under these permits is considered a point source and therefore is included in the WLA portion of a TMDL (EPA 2014; see 40 CFR § 130.2(h)). There are no wastewater facilities that discharge to the Duluth Urban Area impairments and therefore no calculated WLA for wastewater.

Municipal Separate Storm Sewer Systems

There are eight regulated MS4s in the TSS impaired watersheds (Table 36). The regulated areas of the permitted cities and townships within each impaired water were approximated using the developed land cover classes in the jurisdictional boundary of the city or township (see Figure 3 and Table 6 for developed land cover classes; Appendix C includes maps of each MS4 area). The MS4 permits for the regulated road authorities apply to roads within the U.S. Census Bureau Urban Area. The regulated roads and rights-of-way for St. Louis County were approximated by the county road lengths (county and county state aid highways in MnDOT's STREETS_LOAD shapefile) in the 2010 Urban Area multiplied by an average right-of-way width. The regulated roads and rights-of-way within MnDOT's jurisdiction were provided by MnDOT. The UMD regulated area was obtained from their Stormwater Pollution Prevention Program documentation.

The MS4 WLAs were calculated as follows:

MS4 watershed runoff LA *= (Loading capacity – MOS – industrial and construction stormwater WLA – near-channel* LA*) x percent MS4 watershed area*

MS4 regulated areas in each impairment watershed is presented in Appendix C.

Table 36. Regulated MS4s in TSS-impaired watersheds

TSS-impaired Reach Name	Regulated MS4							
	Duluth (MS400086)[a]	Hermantown (MS400093)[a]	Midway Township (MS400146)[a]	Proctor (MS400114)[a]	Rice Lake (MS400151)[a]	University of Minnesota, Duluth (MS400214)[a]	St. Louis County (MS400158)	MnDOT Outstate District (MS400180)
Kingsbury Creek	✓	✓	✓	✓			✓	✓
Amity Creek	✓				✓		✓	
Amity Creek, East Branch	✓				✓		✓	
Lester River	✓				✓	✓	✓	✓

a. Regulated MS4 area represented by developed lands.

Construction and Industrial Stormwater

Construction stormwater and industrial stormwater are NPDES/SDS regulated sources of TSS in the Duluth Urban Area Subwatershed (Construction Stormwater General Permit MNR100001 and Industrial Stormwater General Permit MNR050000). Categorical WLAs for construction and industrial stormwater regulated through the general permits are provided for each TSS TMDL. The average annual (2010 through 2015) percent area of St. Louis County that is regulated through the construction stormwater permit is 0.01% (Minnesota Stormwater Manual contributors 2017). The construction stormwater WLA was calculated as the loading capacity (or TMDL) minus the MOS multiplied by the percent area:

construction stormwater WLA = (TMDL – MOS) x 0.01%

There are two industrial stormwater sites permitted through the general industrial permit in TSS-impaired watersheds: Equipment Rental Co (MNR053D22) and Hartel's/DBJ Disposal Companies (MNRNE38MW). To account for existing and any potential future industrial activities in the TSS impairment subwatersheds, a conservative estimate equal to the construction stormwater WLA was allocated to the industrial stormwater sites that are permitted through the general permit.

Wisconsin Central Ltd. (MN0000361) is an industrial stormwater facility with an individual permit located along Kingsbury Creek. The facility has an existing TSS permit limit of 30 mg/L and discharges to Kingsbury Creek (Section 3.4).

The regulated area of Wisconsin Central Ltd. (229 acres) was approximated using the developed land cover classes within the facility boundary; this is the same approach as was used to approximate the MS4 regulated areas. The WLA for Wisconsin Central Ltd. was calculated as follows:

Wisconsin Central Ltd. watershed runoff WLA = (Loading capacity – MOS – industrial and construction stormwater WLA – near-channel LA) x percent watershed area

Successful implementation of the following actions will demonstrate consistency with the TMDL's assumptions and requirements with respect to Wisconsin Central Ltd.'s WLA:

- Compliance with the NPDES/SDS permit's 30 mg/L TSS effluent limitations;

- Improved snow removal management in order to reduce the amount of sediment that reaches water bodies;
- Reduced streambank erosion along Kingsbury Creek as it flows along the Wisconsin Central Ltd. Site.

Future NPDES/SDS permits for the facility will contain best management practice (BMP) implementation requirements consistent with the assumptions and requirements of the WLA.

Margin of Safety

The Duluth Urban Area HSPF model was calibrated and validated using 15 stream flow gaging stations (Tetra Tech 2019, see Appendix A). Three of the gages had 10 years of continuous data, and the remainder have one to five years of flow records. Many in-stream water quality stations were used for the sediment calibration. Calibration results indicate that the HSPF model is a valid representation of hydrologic and sediment conditions between 1995 and 2016 in the watershed. However, uncertainties exist for many of the gaged and un-gaged streams with regard to simulating flow due to a lack of winter flow monitoring data (needed to understand low winter flows and high flows during melt conditions), and a lack of data to understand the effect of the massive flood in 2012 on predicting future flows and sediment loadings. The 2012 flood changed the geomorphology of many streams in the area.

The TMDL load duration curves were developed using HSPF-simulated daily flow. An explicit MOS of 10% was included in the TSS TMDLs to account for uncertainty that the pollutant allocations would attain the water quality targets. The use of an explicit MOS accounts for environmental variability in pollutant loading, limitations and variability in water quality monitoring data, calibration and validation processes of modeling efforts, and uncertainty in modeling outputs.

Seasonal Variation and Critical Conditions

The CWA requires that TMDLs take into account critical conditions for flow, loading, and water quality parameters as part of the analysis of loading capacity. Both seasonal variation and critical conditions are accounted for through the application of load duration curves. Load duration curves evaluate water quality conditions across all flow regimes including high flow, which is the condition where pollutant transport and loading from upland and near-channel sources tend to be greatest, and low flow, when loading from direct sources to the water bodies has the greatest impact. Seasonality is accounted for by addressing all flow conditions in a given reach. Seasonal variation is also addressed by the water quality standards' application during the period when high pollutant concentrations are expected.

4.1.2 TMDL Summaries

Kingsbury Creek (04010201-626)

The load duration curve and TMDL allocation for Kingsbury Creek are presented in Figure 69 and Table 37, respectively. Table 38 summarizes the TSS reductions needed by source based on the HSPF TMDL model scenario. A 60% reduction is needed from all developed land in the watershed and a 60% reduction is needed from near-channel loads.

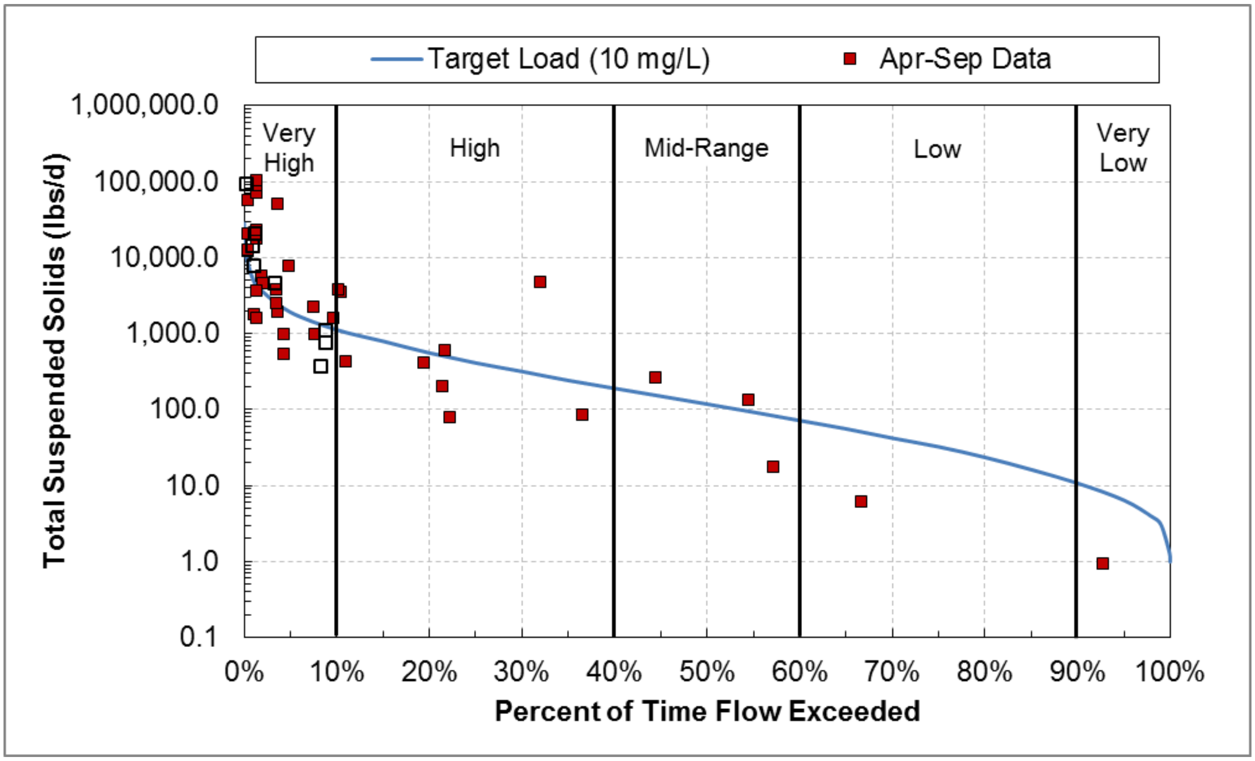


Figure 69. TSS load duration curve, Kingsbury Creek (04010201-626).
Hollow points indicate samples during months when the standard does not apply.

Table 37. TSS TMDL Summary, Kingsbury Creek (04010201-626)

TMDL Parameter		Flow Regime				
		Very High (21–523 cfs)	High (4–21 cfs)	Mid-Range (1–4 cfs)	Low (0.2–1 cfs)	Very Low (0.02–0.2 cfs)
		TSS Load (lbs/day)				
Wasteload Allocation	Wisconsin Central Ltd (MN0000361) [a]	42	9.1	2.6	0.71	0.14
	Duluth City MS4 (MS400086)	47	10	2.9	0..79	0.16
	Hermantown City MS4 (MS400093)	44	9.5	2.7	0.74	0.15
	Midway Township MS4 (MS400146)	26	5.6	1.6	0.44	0.088
	Proctor City MS4 (MS400114)	108	23	6.6	1.8	0.36
	St. Louis County MS4 (MS400158)	13	2.8	0.81	0.22	0.044
	MnDOT Outstate District MS4 (MS400180)	16	3.3	0.96	0.26	0.052
	Industrial Stormwater (MNR050000) [b]	0.17	0.037	0.011	0.0029	0.00058
	Construction Stormwater (MNR100001) [b]	0.17	0.037	0.011	0.0029	0.00058
Load Allocation	Near-channel	611	132	38	10	2.0
	Non-MS4 watershed runoff	813	175	50	14	2.7
MOS		191	41	12	3.2	0.64
Loading Capacity		**1,912**	**412**	**118**	**32**	**6.4**

a. See *Construction and Industrial Stormwater* in Section 4.1.1 for details on actions needed to demonstrate consistency with Wisconsin Central Ltd.'s WLA.

b. It is assumed that loads from permitted construction and industrial stormwater sites that operate in compliance with general permits are meeting the WLA

Table 38. Percent reduction needed to meet TMDL allocations, Kingsbury Creek (04010201-626)

Source	TSS Reduction (average annual)
Industrial Stormwater (general permit)	0%
Construction Stormwater (general permit)	0%
Near-channel	60%
Unregulated Watershed - Undeveloped Land Covers	0%
Unregulated Watershed Runoff- Developed Land Covers	60%
Wisconsin Central Ltd., Industrial Stormwater	60%
MS4 Reductions - Developed Land Covers	
Duluth City MS4	60%
Hermantown City MS4	60%
Midway Township MS4	60%
Proctor City MS4	60%
St. Louis County MS4	60%
MnDOT Outstate District MS4	60%

Amity Creek (04010102-511)

The load duration curve and TSS TMDL allocation for Amity Creek are presented in Figure 70 and Table 39, respectively. Table 39 summarizes the TSS reductions needed by source based on the HSPF TMDL model scenario. A 60% reduction is needed from all developed land in the watershed and a 60% reduction is needed from near-channel loads.

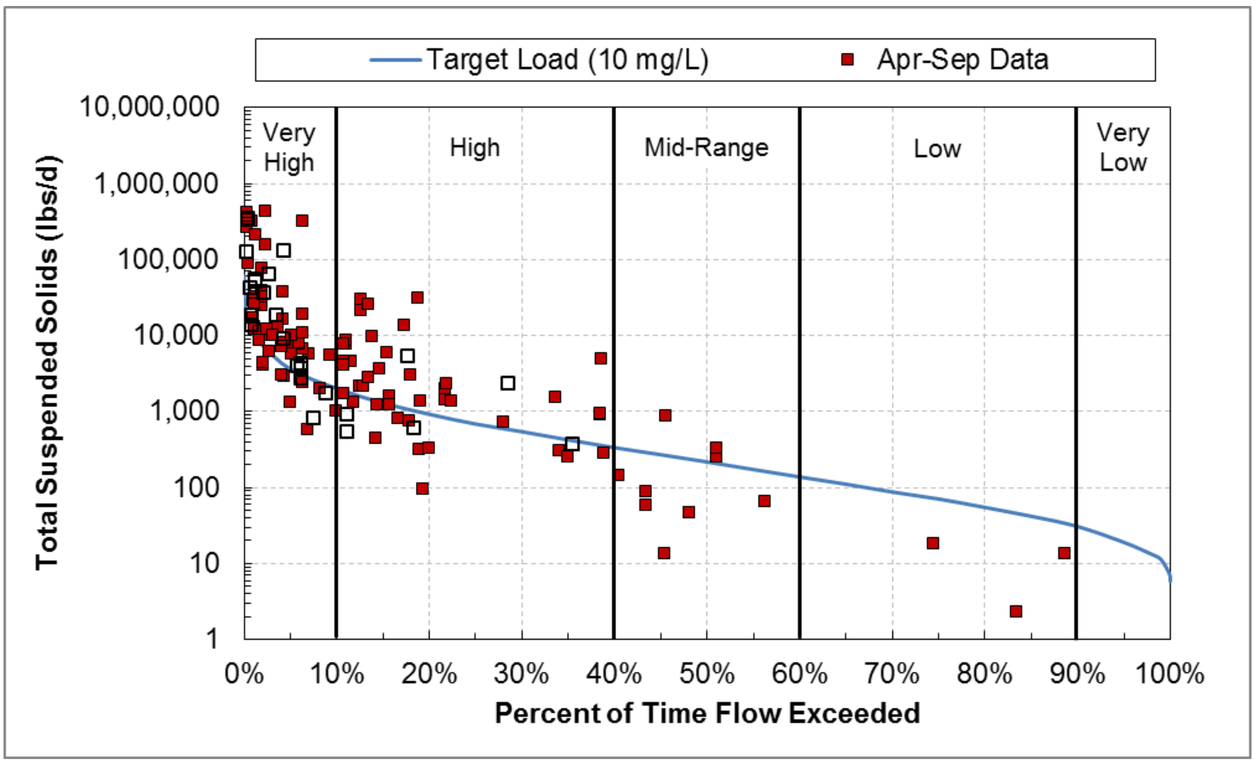


Figure 70. TSS load duration curve, Amity Creek (04010102-511).
Hollow points indicate samples during months when the standard does not apply.

Table 39. TSS TMDL Summary, Amity Creek (04010102-511).

TMDL Parameter		Flow Regime				
		Very High (37–1,128 cfs)	High (6–37 cfs)	Mid-Range (3–6 cfs)	Low (0.6–3 cfs)	Very Low (0.1–0.6 cfs)
		TSS Load (lbs/day)				
Wasteload Allocation	Duluth City MS4 (MS400086)	135	26	8.2	2.7	0.71
	Rice Lake City MS4 (MS400151)	124	24	7.5	2.4	0.65
	St. Louis County MS4 (MS400158)	5.6	1.1	0.34	0.11	0.030
	Industrial Stormwater (MNR050000) [a]	0.32	0.062	0.020	0.0064	0.0017
	Construction Stormwater (MNR100001) [a]	0.32	0.062	0.020	0.0064	0.0017
Load Allocation	Near-channel	1,030	197	62	20	5.4
	Non-MS4 watershed runoff	1,955	373	118	38	10
MOS		361	69	22	7.1	1.9
Loading Capacity		**3,611**	**689**	**218**	**71**	**19**

a. It is assumed that loads from permitted construction and industrial stormwater sites that operate in compliance with the permits are meeting the WLA.

-: No data

Table 40. Percent reduction needed to meet TMDL allocations, Amity Creek (04010102-511).

Source	**Reduction (average annual)**
Industrial Stormwater	0%
Construction Stormwater	0%
Near-channel	60%
Non-MS4 Runoff - Undeveloped Land Covers	0%
Non-MS4 Runoff - Developed Land Covers	60%
MS4 Reductions	
Duluth City MS4	60%
Rice Lake City MS4	60%
St. Louis County MS4	60%

Amity Creek, East Branch (04010102-540)

The load duration curve and TMDL allocation for East Branch Amity Creek are presented in Figure 71 and Table 41, respectively. Table 42 summarizes the TSS reductions needed by source based on the HSPF TMDL model scenario. A 60% reduction is needed from all developed land in the watershed and a 60% reduction is needed from near-channel loads.

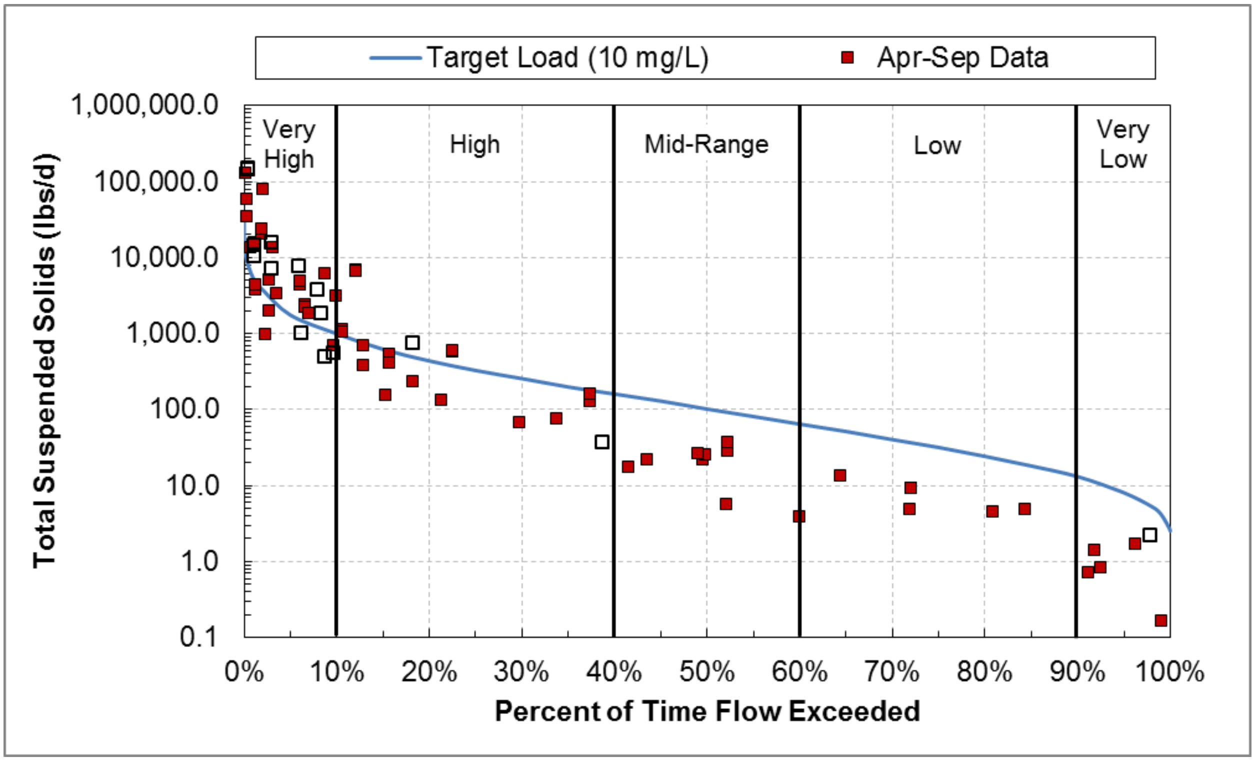


Figure 71. TSS load duration curve, Amity Creek, East Branch (04010102-540).
Hollow points indicate samples during months when the standard does not apply.

Table 41. TSS TMDL Summary, Amity Creek, East Branch (04010102-540).

TMDL Parameter		Flow Regime				
		Very High (18–540 cfs)	High (3–18 cfs)	Mid-Range (1–3 cfs)	Low (0.2–1 cfs)	Very Low (0.05–0.2 cfs)
		TSS Load (lbs/day)				
Wasteload Allocation	Duluth City MS4 (MS400086)	24	4.6	1.4	0.44	0.11
	Rice Lake City MS4 (MS400151)	90	17	5.2	1.6	0.42
	St. Louis County MS4 (MS400158)	1.9	0.35	0.11	0.034	0.0086
	Industrial Stormwater (MNR050000) [a]	0.16	0.030	0.0092	0.0029	0.00073
	Construction Stormwater (MNR100001) [a]	0.16	0.030	0.0092	0.0029	0.00073
Load Allocation	Near-channel	332	62	19	6.0	1.5
	Non-MS4 watershed runoff	1,133	211	66	21	5.2
MOS		176	33	10	3.2	0.81
Loading Capacity		**1,758**	**328**	**102**	**32**	**8.1**

a. It is assumed that loads from permitted construction and industrial stormwater sites that operate in compliance with the permits are meeting the WLA.

Table 42. Percent reduction needed to meet TMDL allocations, Amity Creek, East Branch (04010102-540).

Source	Reduction (average annual)
Industrial Stormwater	0%
Construction Stormwater	0%
Near-channel	60%
Non-MS4 Runoff - Undeveloped Land Covers	0%
Non-MS4 Runoff - Developed Land Covers	60%
MS4 Reductions	
Duluth City MS4	60%
Rice Lake City MS4	60%
St. Louis County MS4	60%

Lester River (04010102-549)

The load duration curve and TMDL allocation for the Lester River are presented in Figure 72 and Table 43, respectively. Table 44 summarizes the TSS reductions needed by source based on the HSPF TMDL model scenario. A 60% reduction is needed from all developed land in the watershed and a 60% reduction is needed from near-channel loads in all reaches, with the exception of the most downstream reach which requires a 90% reduction in near-channel sources.

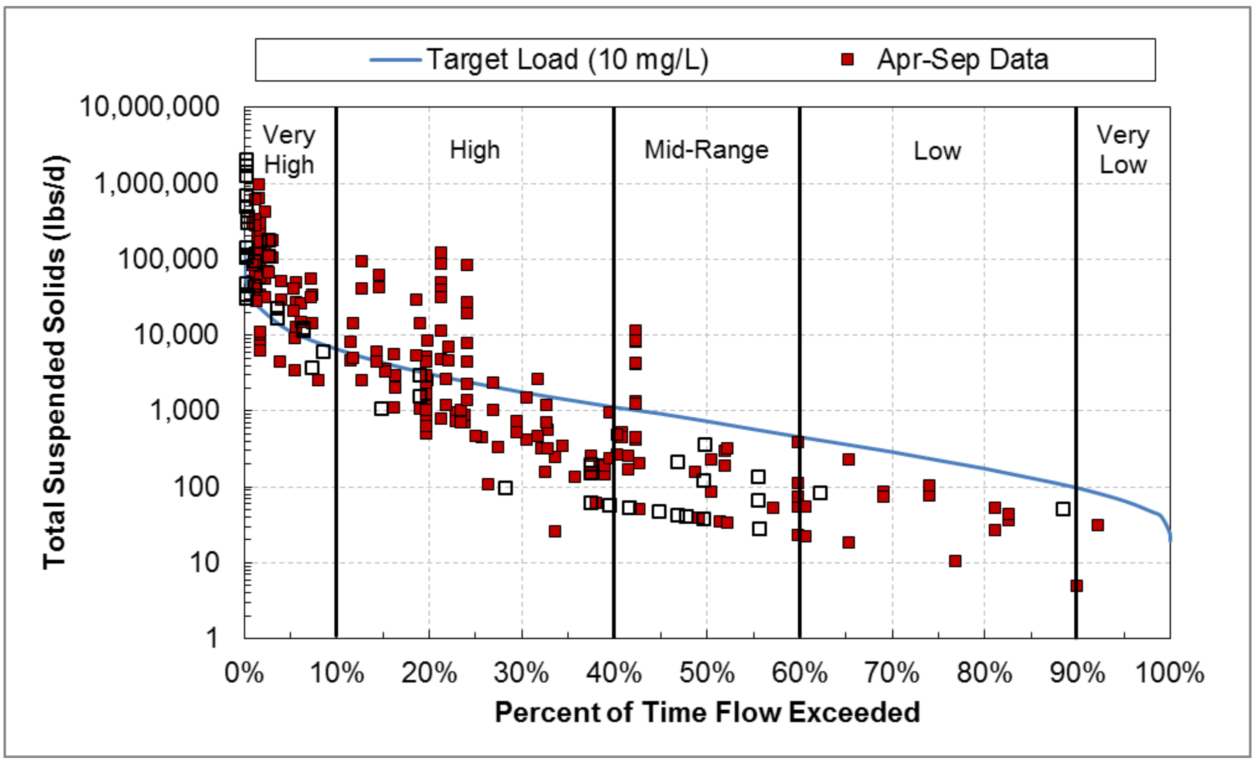


Figure 72. TSS load duration curve, Lester River (04010102-549).
Hollow points indicate samples during months when the standard does not apply.

Table 43. TSS TMDL Summary, Lester River (04010102-549).

TMDL Parameter		Very High (122–3,259 cfs)	High (21–122 cfs)	Mid-Range (8–21 cfs)	Low (2–8 cfs)	Very Low (0.4–2 cfs)
		Flow Regime				
		TSS Load (lbs/day)				
Wasteload Allocation	Duluth City MS4 (MS400086)	137	28	8.9	2.7	0.80
	Rice Lake City MS4 (MS400151)	150	31	9.8	3.0	0.88
	University of Minnesota, Duluth MS4 (MS400214)	0.029	0.0059	0.0019	0.00057	0.00017
	St. Louis County MS4 (MS400158)	5.3	1.1	0.3	0.11	0.031
	MnDOT Outstate District MS4 (MS400180)	0.13	0.026	0.0083	0.0025	0.00074
	Industrial Stormwater (MNR050000) [a]	1.0	0.21	0.066	0.020	0.0059
	Construction Stormwater (MNR100001) [a]	1.0	0.21	0.066	0.020	0.0059
Load Allocation	Near-channel	3,484	719	228	70	21
	Non-MS4 watershed runoff	6,323	1,305	414	126	37
MOS		1,122	232	74	22	6.6
Loading Capacity		**11,222**	**2,316**	**735**	**224**	**66**

a. It is assumed that loads from permitted construction and industrial stormwater sites that operate in compliance with the permits are meeting the WLA.

Table 44. Percent reduction needed to meet TMDL allocations, Lester River (04010102-549).

Source	Reduction (average annual)
Industrial Stormwater	0%
Construction Stormwater	0%
Near-channel	60% [a]
Non-MS4 Runoff - Undeveloped Land Covers	0%
Non-MS4 Runoff - Developed Land Covers	60%
MS4 Reductions	
Duluth City MS4	60%
Rice Lake City MS4	60%
University of Minnesota, Duluth MS4	60%
St. Louis County MS4	60%
MnDOT Outstate District MS4	60%

a. In addition, a 90% reduction in near-channel sources in needed in the most downstream reach of Lester River to achieve compliance with water quality standards.

4.2 *E. coli*

4.2.1 Approach

Loading Capacity

The loading capacity for *E. coli* is based on the monthly geometric mean standard (126 org/100 mL). It is assumed that practices that are implemented to meet the geometric mean standard will also address the individual sample standard (1,260 org/100 mL). The loading capacity is calculated as flow multiplied by the *E. coli* standard (126 org/100 mL). The loading capacities and allocations are rounded to two significant digits, except in the case of values greater than 100, which are rounded to the nearest whole number.

Load Reduction

Percent reductions for *E. coli* TMDLs are provided based on monitored concentration data and the water quality standard. Ideally, sufficient data would exist to calculate actual *E. coli* loads to compare directly to the TMDLs, which would allow for load reduction projections. However, the amount of data required for load calculations is much greater than that required for simple impairment assessment. As such, a load reduction is not provided. Instead, the estimated percent reduction provided for each TMDL was calculated by comparing the highest observed (monitored) monthly geometric mean concentration from the months that the standard applies to the geometric mean standard, as a concentration, (monitored – standard/monitored). The estimated percent reductions provide a rough approximation of the overall reduction needed for the water body to meet the TMDL. The percent reductions should not be construed to mean that each of the separate sources listed in the TMDL table need to be reduced by that amount. The percent reduction should be interpreted as a means to capture the level of effort needed to reduce *E. coli* concentrations in the watershed. Calculations come from the best available data and support the conclusion that *E. coli* sources need to be addressed.

Baseline Year

The monitoring data used to support TMDL development are from 2007 through 2016. Because projects undertaken recently may take a few years to influence water quality, the baseline year for crediting load reductions for a given water body is 2011, the midpoint of the time period. Any activities implemented during or after the baseline year that led to a reduction in pollutant loads to the waterbodies may be considered as progress towards meeting a WLA or LA.

Load Allocation

The LA represents the portion of the loading capacity that is allocated to pollutant loads that are not regulated through an NPDES/SDS permit, and is calculated as the loading capacity minus the sum of the WLAs and the MOS. The LA covers watershed runoff that is generated in areas that are not regulated through an NPDES/SDS permit, along with other nonpoint sources such as septic systems. The LA also includes natural background sources of *E. coli* as described in Section 4.1.1. Natural background sources of *E. coli* would include wildlife and naturalized strains of *E. coli*. Quantifying these sources was not possible, and therefore it was also not possible to determine the amount of the LA that should be designated to natural background.

Wasteload Allocation

The WLA represents the portion of the loading capacity that is allocated to pollutant loads that are regulated through an NPDES/SDS permit. There are no permitted point sources in the watershed that require an *E. coli* WLA except for regulated MS4s. Permitted construction and industrial stormwater sources are not expected to be sources of *E. coli* and are not provided WLAs. There are no permitted CAFOs in the watershed.

There are nine regulated MS4s in the *E. coli* impairment watersheds (Table 45 and Appendix C). The regulated area within the watershed of each impaired water was approximated using developed land cover classes in the jurisdictional boundary of the city or township (see Figure 3 and Table 6 for developed land cover classes). The MS4 WLAs were calculated as the percent coverage of the regulated MS4 multiplied by the loading capacity minus the MOS. The MS4 regulated area within each impairment watershed is presented in Appendix C.

Table 45. Regulated MS4s in *E. coli*-impaired watersheds.

E. coli-impaired Reach Name	Regulated MS4								
	Duluth (MS400086)[a]	Hermantown (MS400093)[a]	Midway Township (MS400146)[a]	Proctor (MS400114)[a]	Rice Lake (MS400151)[a]	Lake Superior College (MS400225)[a]	University of Minnesota, Duluth (MS400214)[a]	St. Louis County (MS400158)	MnDOT Outstate District (MS400180)
Keene Creek	✓	✓						✓	✓
Miller Creek	✓	✓			✓	✓	✓	✓	✓
Sargent Creek	✓		✓						✓
Stewart Creek	✓		✓	✓					✓
Unnamed creek (Merritt Creek)	✓	✓						✓	✓
Tischer Creek	✓				✓		✓	✓	✓
Chester Creek	✓				✓		✓	✓	✓

a. Regulated MS4 area represented by developed lands.

Margin of Safety

The Duluth Urban Area HSPF model was calibrated and validated using 15 stream flow gaging stations (Tetra Tech 2019, see Appendix A). Three of the gages had 10 years of continuous data, and the remainder have one to five years of flow records. Calibration results indicate that the HSPF model is a valid representation of hydrologic conditions between 1995 and 2016 in the watershed. However, uncertainties exist for many of the gaged and un-gaged streams with regard to simulating flow, due to a lack of winter flow monitoring data (needed to understand low winter flows and high flows during melt conditions).

The TMDL load duration curves were developed using HSPF-simulated daily flow data. An explicit MOS of 10% was included in the *E. coli* TMDLs to account for uncertainty that the pollutant allocations would attain the water quality targets. The use of an explicit MOS accounts for environmental variability in pollutant loading, limitations and variability in water quality monitoring data, calibration and validation processes of modeling efforts, and uncertainty in modeling outputs. In addition, die-off and instream growth of *E. coli* were not explicitly addressed. The MOS helps to account for variability in *E. coli* concentrations associated with growth and die-off.

Seasonal Variation and Critical Conditions

The CWA requires that TMDLs take into account critical conditions for flow, loading, and water quality parameters as part of the analysis of loading capacity. Both seasonal variation and critical conditions are accounted for through the application of load duration curves. Load duration curves evaluate water quality conditions across all flow regimes including high flow, which is the condition where pollutant transport and loading from upland sources tend to be greatest, and low flow, when loading from direct sources to the water bodies have the greatest impact. Seasonal variations are also addressed in this TMDL by assessing conditions only during the season when the water quality standard applies (April 1 through October 31).

4.2.2 TMDL Summaries

Keene Creek (04010201-627)

The load duration curve and TMDL allocations for Keene Creek are presented in Figure 73 and Table 46, respectively. Load reductions are needed under all flow conditions. The largest load reductions are needed under very high flow conditions.

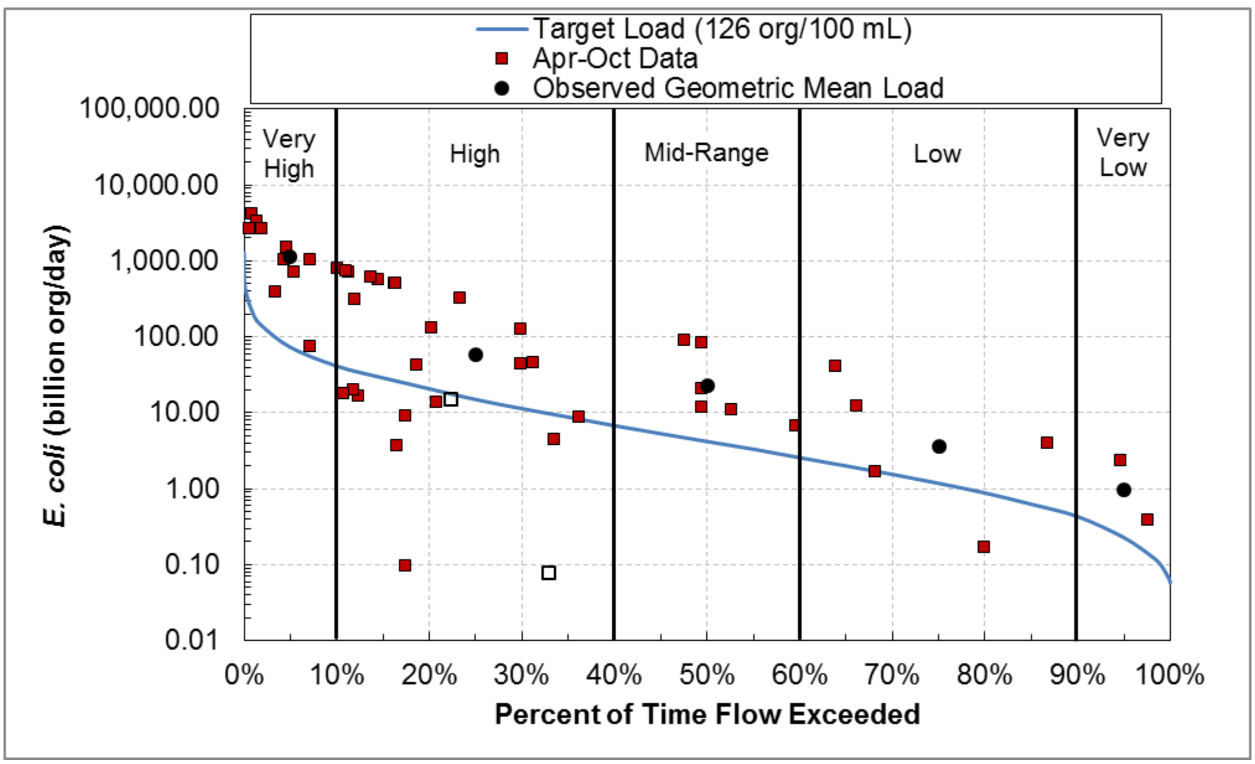


Figure 73. *E. coli* load duration curve, Keene Creek (04010201-627).
Hollow points indicate samples during months when the standard does not apply.

Table 46. *E. coli* TMDL summary, Keene Creek (04010201-627).

TMDL Parameter		Very High (13–412 cfs)	High (2–13 cfs)	Mid-Range (0.8–2 cfs)	Low (0.1–0.8 cfs)	Very Low (0.02–0.1 cfs)
		E. coli Load (billion org/day)				
Wasteload Allocation	Duluth City MS4 (MS400086)	9.1	1.9	0.52	0.15	0.029
	Hermantown City MS4 (MS400093)	6.1	1.3	0.35	0.10	0.019
	St. Louis County MS4 (MS400158)	0.76	0.16	0.044	0.013	0.0024
	MnDOT Outstate District MS4 (MS400180)	0.95	0.20	0.055	0.016	0.0030
Load Allocation		49	10	2.8	0.80	0.15
MOS		7.3	1.5	0.42	0.12	0.023
Loading Capacity		**73**	**15**	**4.2**	**1.2**	**0.23**
Maximum monthly geomean (org/100 mL)		961				
Overall estimated percent reduction [a]		87%				

a. Calculated by comparing the highest observed (monitored) monthly geometric mean concentration from the months that the standard applies to the geometric mean standard, as a concentration, (monitored – standard/monitored). See Section 3.3 for more information.

Miller Creek (04010201-512)

The load duration curve and TMDL allocation for Miller Creek are presented in Figure 74 and Table 47, respectively. Load reductions are needed under all flow conditions; the largest load reductions are needed under high flows.

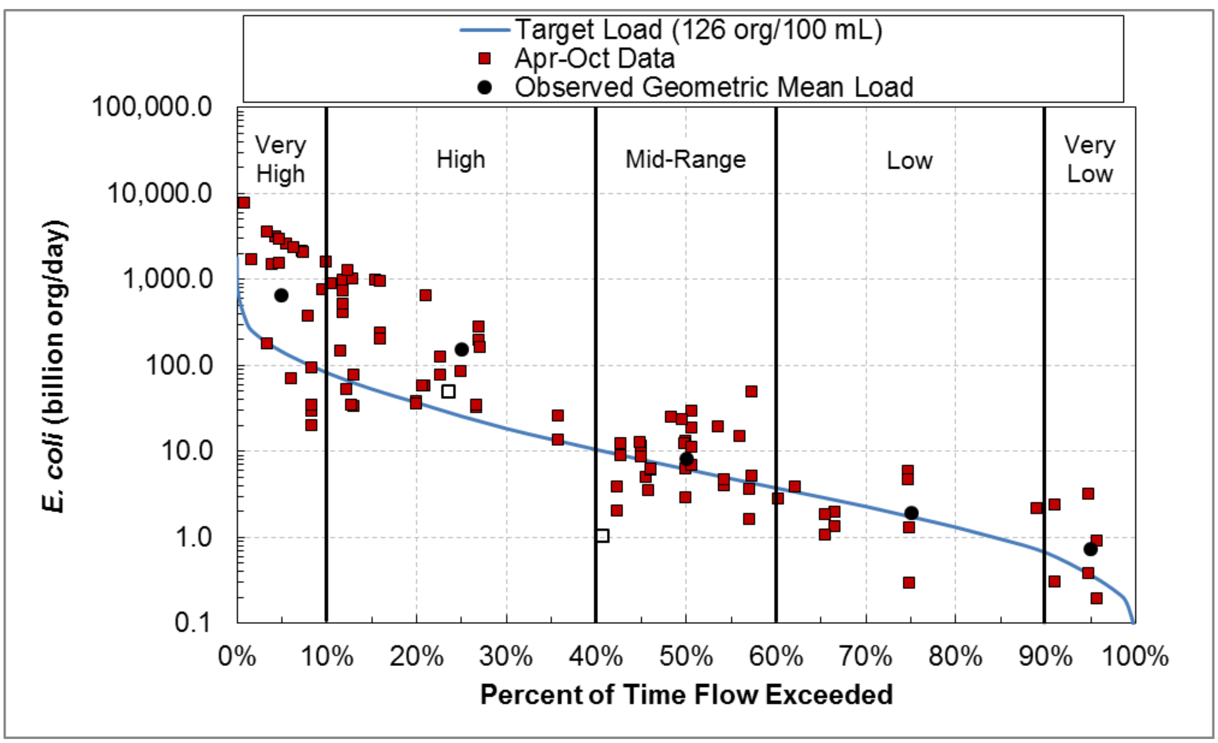


Figure 74. *E. coli* load duration curve, Miller Creek (04010201-512).

Hollow points indicate samples during months when the standard does not apply.

Table 47. *E. coli* TMDL summary, Miller Creek (04010201-512).

TMDL Parameter		Very High (27–574 cfs)	High (3–27 cfs)	Mid-Range (1–3 cfs)	Low (0.2–1 cfs)	Very Low (0.02–0.2 cfs)
		E. coli Load (billion org/day)				
Wasteload Allocation	Duluth City MS4 (MS400086)	39	7.3	1.7	0.48	0.10
	Hermantown City MS4 (MS400093)	12	2.2	0.53	0.15	0.031
	Rice Lake City MS4 (MS400151)	1.0	0.18	0.044	0.012	0.0025
	Lake Superior College MS4 (MS400225)	0.55	0.10	0.025	0.0067	0.0014
	University of Minnesota, Duluth MS4 (MS400214)	0.13	0.025	0.0060	0.0016	0.00035
	St. Louis County MS4 (MS400158)	1.6	0.31	0.073	0.020	0.0042
	MnDOT Outstate District MS4 (MS400180)	3.1	0.57	0.14	0.037	0.0079
Load Allocation		69	13	3.1	0.82	0.18
MOS		14	2.6	0.62	0.17	0.036
Loading Capacity		**140**	**26**	**6.2**	**1.7**	**0.36**
Maximum monthly geomean (org/100 mL)		418				
Overall estimated percent reduction [a]		70%				

a. Calculated by comparing the highest observed (monitored) monthly geometric mean concentration from the months that the standard applies to the geometric mean standard, as a concentration, (monitored – standard/monitored). See Section 3.3 for more information.

Sargent Creek (04010201-848)

The load duration curve and TMDL allocation for Sargent Creek are presented in Figure 75 and Table 48, respectively. Samples were not collected under very high flow conditions and only one sample was collected under very low flow conditions.

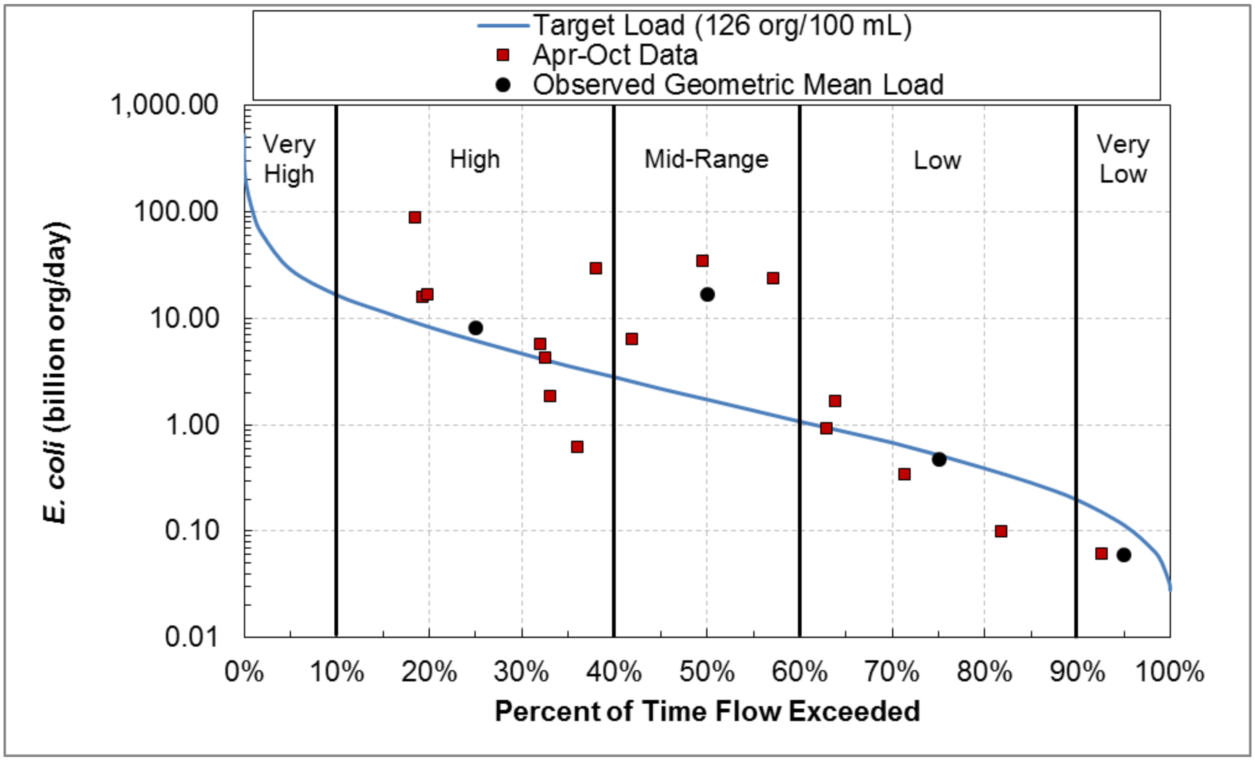


Figure 75. *E. coli* load duration curve, Sargent Creek (04010201-848).

Table 48. *E. coli* TMDL summary, Sargent Creek (04010201-848).

TMDL Parameter		Flow Regime				
		Very High (5–172 cfs)	High (0.9–5 cfs)	Mid-Range (0.3–0.9 cfs)	Low (0.06–0.3 cfs)	Very Low (0.009–0.06 cfs)
		E. coli Load (billion org/day)				
Wasteload Allocation	Duluth City MS4 (MS400086)	1.9	0.40	0.11	0.034	0.0072
	Midway Township MS4 (MS400146)	0.51	0.11	0.030	0.0091	0.0019
	MnDOT Outstate District MS4 (MS400180)	0.11	0.023	0.0064	0.0019	0.00041
Load Allocation		24	5.0	1.4	0.42	0.089
MOS		2.9	0.62	0.17	0.052	0.011
Loading Capacity		29	6.2	1.7	0.52	0.11
Maximum monthly geomean (org/100 mL)		228				
Overall estimated percent reduction [a]		45%				

-: No data

a. Calculated by comparing the highest observed (monitored) monthly geometric mean concentration from the months that the standard applies to the geometric mean standard, as a concentration, (monitored – standard/monitored). See Section 3.3 for more information.

Stewart Creek (04010201-884)

The load duration curve and TMDL allocation for Stewart Creek are presented in Figure 76 and Table 49, respectively. Samples were not collected under very high flow conditions and only one sample was collected under very low flow conditions.

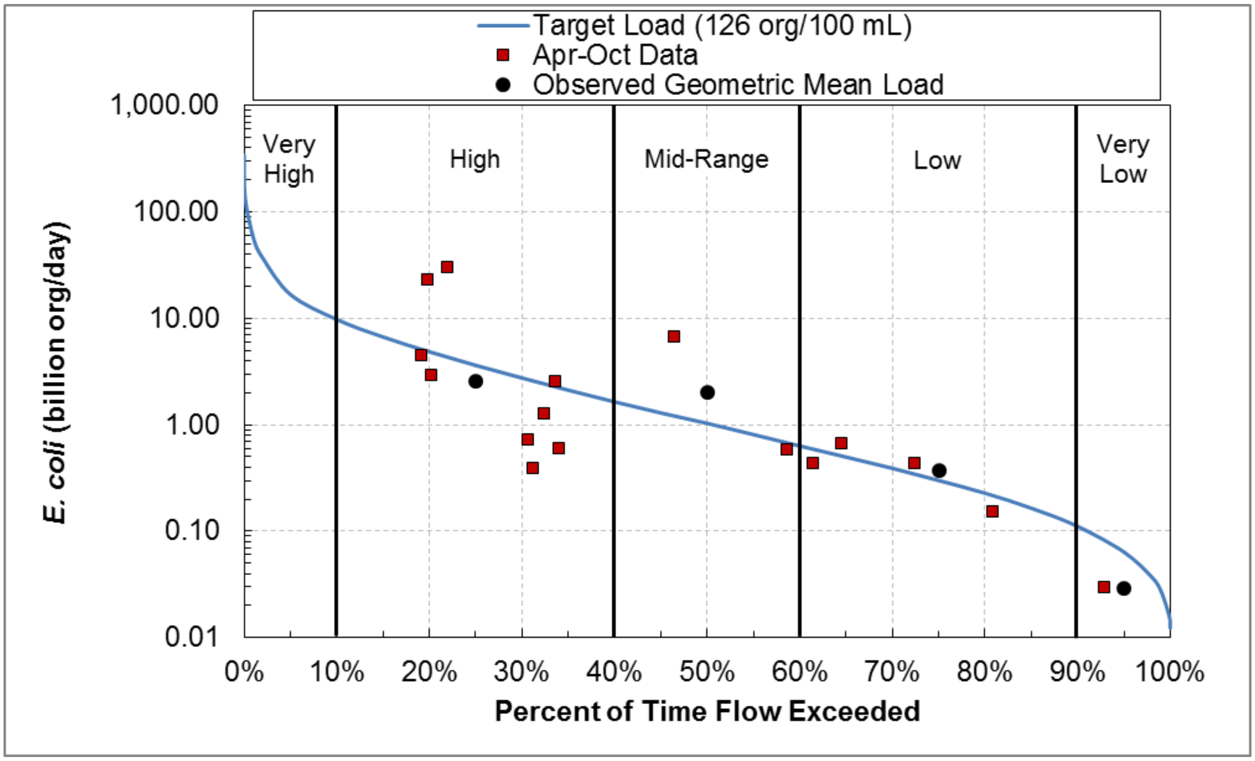


Figure 76. *E. coli* load duration curve, Stewart Creek (04010201-884).

Table 49. *E. coli* TMDL summary, Stewart Creek (04010201-884).

TMDL Parameter		**Flow Regime**				
		Very High (3–111 cfs)	**High (0.5–3 cfs)**	**Mid-Range (0.2–0.5 cfs)**	**Low (0.04–0.2 cfs)**	**Very Low (0.004–0.04 cfs)**
		***E. coli* Load (billion org/day)**				
Wasteload Allocation	Duluth City MS4 (MS400086)	1.3	0.28	0.078	0.024	0.0050
	Midway Township MS4 (MS400146)	0.22	0.047	0.013	0.0039	0.00084
	Proctor City MS4 (MS400114)	0.068	0.014	0.0040	0.0012	0.00026
	MnDOT Outstate District MS4 (MS400180)	0.18	0.039	0.011	0.0032	0.00069
Load Allocation		14	2.9	0.79	0.24	0.051
MOS		1.7	0.36	0.10	0.030	0.0064
Loading Capacity		**17**	**3.6**	**1.0**	**0.30**	**0.064**
Maximum monthly geomean (org/100 mL)		226				
Overall estimated percent reduction [a]		44%				

-: No data

a. Calculated by comparing the highest observed (monitored) monthly geometric mean concentration from the months that the standard applies to the geometric mean standard, as a concentration, (monitored – standard/monitored). See Section 3.3 for more information.

Unnamed Creek (Merritt Creek; 04010201-987)

The load duration curve and TMDL allocation for Unnamed Creek (Merritt Creek) are presented in Figure 77 and Table 50, respectively. The largest load reductions are needed under very high flow conditions.

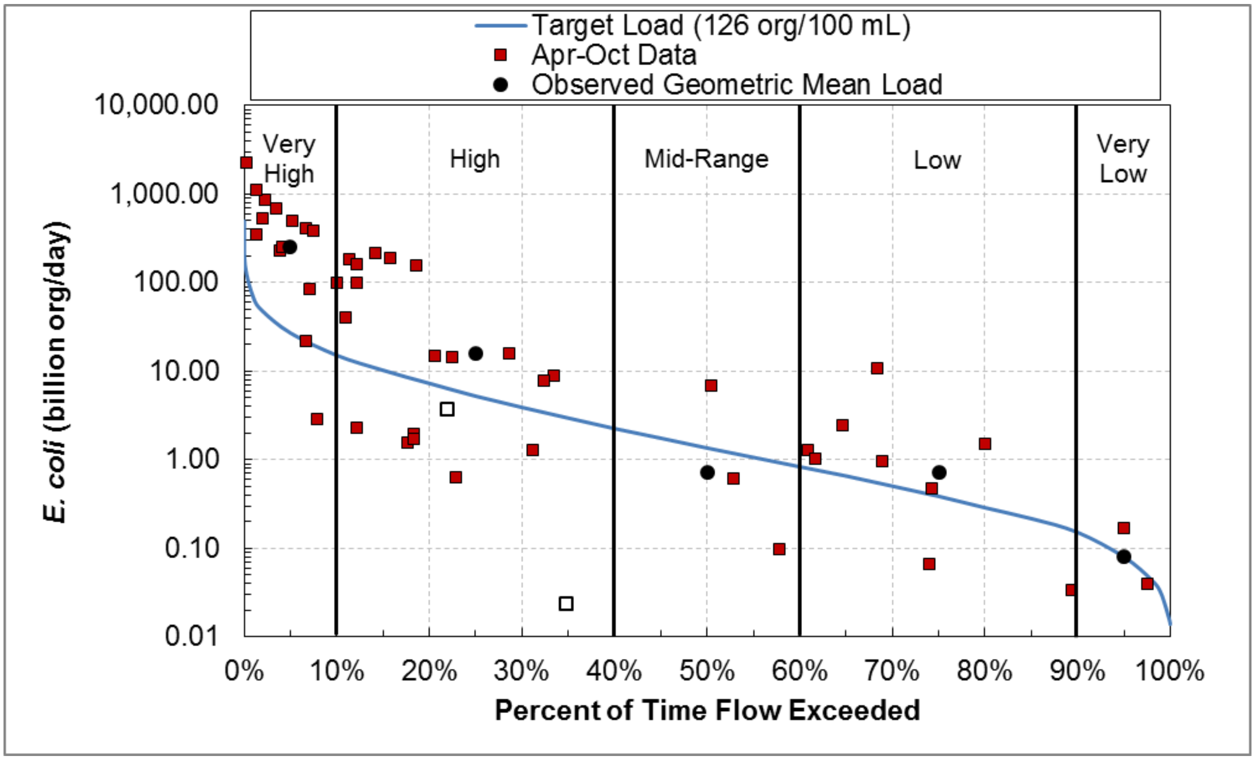


Figure 77. *E. coli* load duration curve, Unnamed Creek (Merritt Creek; 04010201-987).
Hollow points indicate samples during months when the standard does not apply.

Table 50. *E. coli* TMDL summary, Unnamed Creek (Merritt Creek; 04010201-987).

TMDL Parameter		Flow Regime				
		Very High (5–161 cfs)	**High (0.7–5 cfs)**	**Mid-Range (0.3–0.7 cfs)**	**Low (0.05–0.3 cfs)**	**Very Low (0.004–0.05 cfs)**
		***E. coli* Load (billion org/day)**				
Wasteload Allocation	Duluth City MS4 (MS400086)	7.1	1.4	0.37	0.10	0.021
	Hermantown City MS4 (MS400093)	0.63	0.12	0.033	0.0091	0.0019
	St. Louis County MS4 (MS400158)	0.48	0.092	0.025	0.0069	0.0014
	MnDOT Outstate District MS4 (MS400180)	0.41	0.080	0.021	0.0060	0.0012
Load Allocation		16	3.0	0.81	0.23	0.047
MOS		2.7	0.52	0.14	0.039	0.0080
Loading Capacity		**27**	**5.2**	**1.4**	**0.39**	**0.080**
Maximum monthly geomean (org/100 mL)		858				
Overall estimated percent reduction [a]		85%				

a. Calculated by comparing the highest observed (monitored) monthly geometric mean concentration from the months that the standard applies to the geometric mean standard, as a concentration, (monitored – standard/monitored). See Section 3.3 for more information.

Tischer Creek (04010102-544)

The load duration curve and TMDL allocation for Tischer Creek are presented in Figure 78 and Table 51, respectively. Load reductions are needed under all flow conditions; the largest load reductions are needed under high flows.

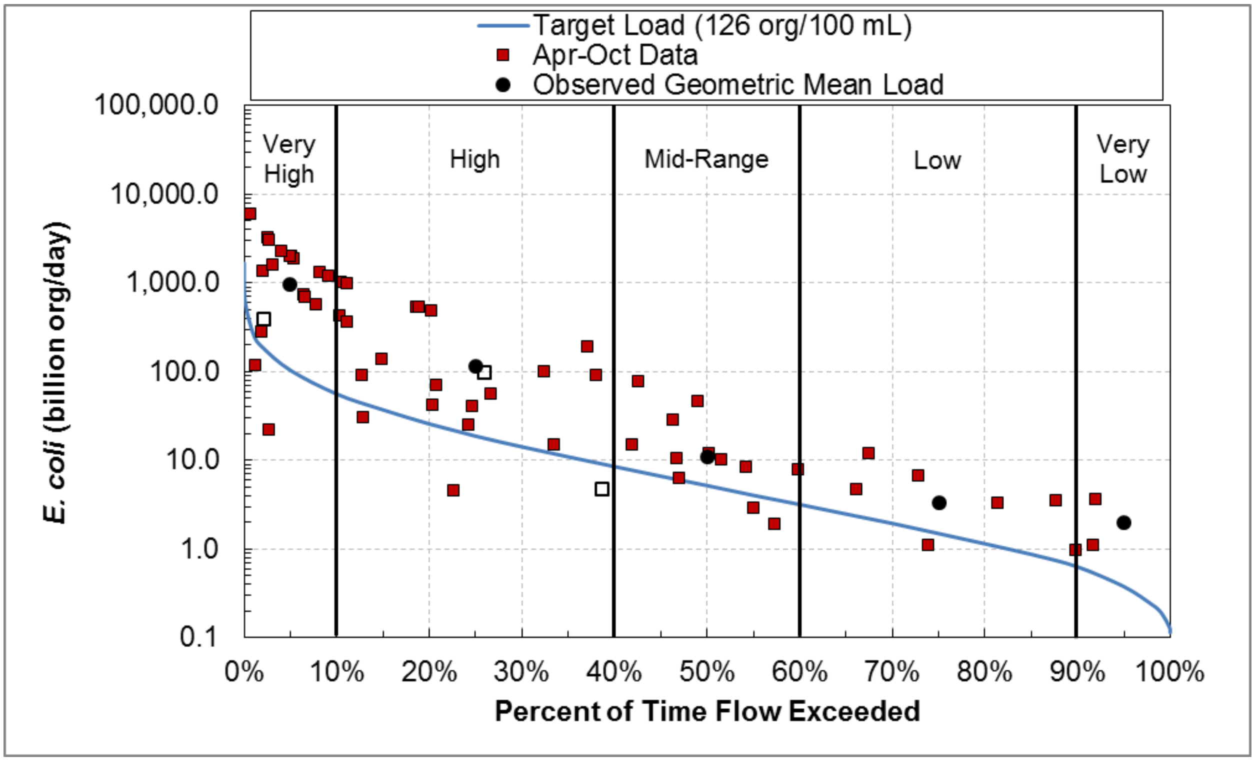


Figure 78. *E. coli* load duration curve, Tischer Creek (04010102-544).
Hollow points indicate samples during months when the standard does not apply.

Table 51. *E. coli* TMDL summary, Tischer Creek (04010102-544).

TMDL Parameter		Very High (18–540 cfs)	High (3–18 cfs)	Mid-Range (1–3 cfs)	Low (0.2–1 cfs)	Very Low (0.04–0.2 cfs)
		***E. coli* Load (billion org/day)**				
Wasteload Allocation	Duluth City MS4 (MS400086)	24	4.4	1.2	0.35	0.088
	Rice Lake City MS4 (MS400151)	6.4	1.2	0.32	0.092	0.023
	University of Minnesota, Duluth MS4 (MS400214)	1.4	0.25	0.070	0.020	0.0051
	St. Louis County MS4 (MS400158)	1.4	0.25	0.067	0.019	0.0049
	MnDOT Outstate District MS4 (MS400180)	0.026	0.0047	0.0013	0.00037	0.000093
Load Allocation		61	11	3.0	0.87	0.22
MOS		10	1.9	0.52	0.15	0.038
Loading Capacity		**104**	**19**	**5.2**	**1.5**	**0.38**
Maximum monthly geomean (org/100 mL)		1,193				
Overall estimated percent reduction [a]		89%				

a. Calculated by comparing the highest observed (monitored) monthly geometric mean concentration from the months that the standard applies to the geometric mean standard, as a concentration, (monitored – standard/monitored). See Section 3.3 for more information.

Chester Creek (04010102-545)

The load duration curve and TMDL allocation for Chester Creek are presented in Figure 79 and Table 52, respectively. Load reductions are needed under all flow conditions.

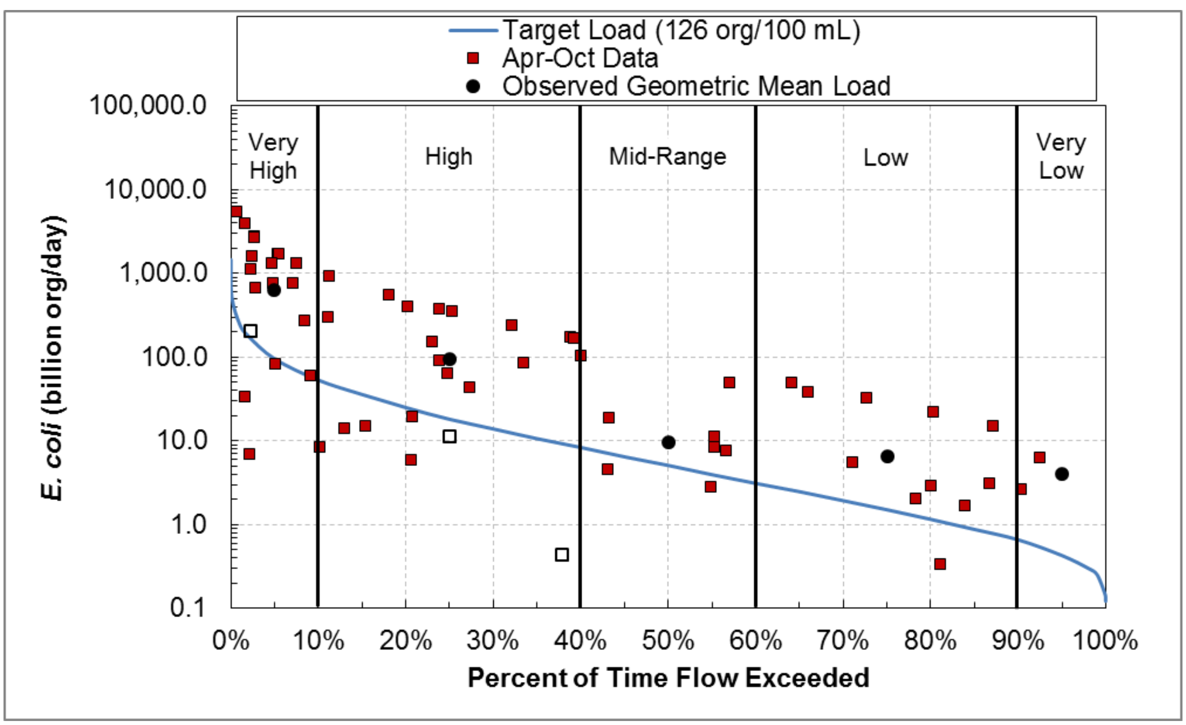


Figure 79. *E. coli* load duration curve, Chester Creek (04010102-545).
Hollow points indicate samples during months when the standard does not apply.

Table 52. *E. coli* TMDL summary, Chester Creek (04010102-545).

TMDL Parameter		Very High (17–474 cfs)	High (3–17 cfs)	Mid-Range (1–3 cfs)	Low (0.2–1 cfs)	Very Low (0.04–0.2 cfs)
		***E. coli* Load (billion org/day)**				
Wasteload Allocation	Duluth City MS4 (MS400086)	24	4.5	1.3	0.38	0.11
	Rice Lake City MS4 (MS400151)	0.24	0.046	0.013	0.0038	0.0011
	University of Minnesota, Duluth MS4 (MS400214)	0.0093	0.0017	0.00049	0.00014	0.000041
	St. Louis County MS4 (MS400158)	0.62	0.12	0.033	0.010	0.0028
	MnDOT Outstate District MS4 (MS400180)	0.030	0.0056	0.0016	0.00047	0.00013
Load Allocation		62	12	3.2	0.96	0.27
MOS		10	1.8	0.51	0.15	0.043
Loading Capacity		**96**	**18**	**5.1**	**1.5**	**0.43**
Maximum monthly geomean (org/100 mL)		1,494				
Overall estimated percent reduction [a]		92%				

Flow Regime columns: Very High, High, Mid-Range, Low, Very Low.

a. Calculated by comparing the highest observed (monitored) monthly geometric mean concentration from the months that the standard applies to the geometric mean standard, as a concentration, (monitored – standard/monitored). See Section 3.3 for more information.

5. Future Growth Considerations

5.1 New or Expanding Permitted MS4 WLA Transfer Process

Future transfer of watershed runoff loads in this TMDL may be necessary if any of the following scenarios occur within the project watershed boundaries:

1. New development occurs within a regulated MS4. Newly developed areas that are not already included in the WLA must be transferred from the LA to the WLA to account for the growth.
2. One regulated MS4 acquires land from another regulated MS4. Examples include annexation or highway expansions. In these cases, the transfer is WLA to WLA.
3. One or more unregulated MS4s become regulated. If this has not been accounted for in the WLA, then a transfer must occur from the LA.
4. Expansion of a U.S. Census Bureau Urban Area encompasses new regulated areas for existing permittees. An example is existing state highways that were outside an Urban Area at the time the TMDL was completed, but are now inside a newly expanded Urban Area. This will require either a WLA to WLA transfer or a LA to WLA transfer.
5. A new MS4 or other stormwater-related point source is identified and is covered under a NPDES/SDS permit. In this situation, a transfer must occur from the LA.

Load transfers will be based on methods consistent with those used in setting the allocations in this TMDL, specifically loads will be transferred on a simple land-area basis. In cases where WLA is transferred from or to a regulated MS4, the permittees will be notified of the transfer and have an opportunity to comment.

5.2 New or Expanding Wastewater

The MPCA, in coordination with the EPA Region 5, has developed a streamlined process for setting or revising WLAs for new or expanding wastewater discharges to water bodies with an EPA approved TMDL (described in Section 3.7.1 *New and Expanding Discharges* in MPCA 2012). This procedure will be used to update WLAs in approved TMDLs for new or expanding wastewater dischargers whose permitted effluent limits are at or below the instream target, and will ensure that the effluent concentrations will not exceed applicable water quality standards or surrogate measures. The process for modifying any and all WLAs will be handled by the MPCA, with input and involvement by the EPA, once a permit request or reissuance is submitted. The overall process will use the permitting public notice process to allow for the public and EPA to comment on the permit changes based on the proposed WLA modification(s). Once any comments or concerns are addressed, and the MPCA determines that the new or expanded wastewater discharge is consistent with the applicable water quality standards, the permit will be issued and any updates to the TMDL WLA(s) will be made.

For more information on the overall process, visit the MPCA's TMDL Policy and Guidance webpage.

6. Reasonable Assurance

The EPA requires reasonable assurance that TMDLs will be achieved and water quality standards will be met. Restoration of the Duluth Urban Area Watershed will occur as part of local, regional, state, and federal efforts and will be led by South St. Louis Soil and Water Conservation District (SWCD), St. Louis County, state agencies, local communities (especially MS4 communities), and residents. In addition, watershed groups such as the Regional Stormwater Protection Team (RSPT), Lake Superior Streams, the Weber Stream Restoration Initiative, Minnesota Sea Grant, the NRRI, and the UMD are active partners in watershed protection and restoration in the watershed.

The Duluth Urban Watershed Advisory Committee (DUWAC) is a voluntary group of stakeholders that provides the opportunity for collaboration, information sharing, and education related to TMDL and WRAPS implementation. The committee was formed in 2015. Currently, there are 32 members. The committee has begun an effort to evaluate local ordinances in regard to green infrastructure development in the watershed.

The RSPT is a collaboration between local MS4s, partnering agencies and organization. It operates under the mission of protecting and enhancing the region's shared water resources through stormwater pollution prevention by providing coordinated educational programs and technical assistance, such as their series of commercials for homeowners and residents. The RSPT also coordinates work days and projects, such as the 250 trees planted along Miller Creek corridor as part of an annual trash collection and tree planting event in May 2016.

The City of Duluth is also active in evaluation and restoration of waters in the Duluth Urban Area. The city has been improving stream crossings and addressing leaky wastewater infrastructure as part of their annual capital improvement plan. They are also active partners in monitoring. MnDOT has also completed many projects in the watershed, such as a natural stream restoration and crossing upgrade along Grand Avenue, and fish passage improvements at Trunk Highway 35 (Kingsbury Creek) and at Trunk Highway 23.

A record of past and on-going activities along with many potential funding sources provides reasonable assurance that progress will be made toward pollutant load reductions and meeting the TMDLs.

Potential funding sources for implementation activities in the watershed include:

- Clean Water Fund, part of the Clean Water, Land, and Legacy Amendment;
- Minnesota's Lake Superior Coastal Program grants;
- State and local government cost-share and loan programs (One Watershed, One Plan [1W1P] targeted funds, Clean Water Partnership Loan Program)
- Federal grants and technical assistance programs (e.g., National Fish and Wildlife Foundation, U.S. Forest Service)
- Federal Clean Water Act Section 319 program for watershed improvements
- Great Lakes Restoration Initiative
- Great Lakes Commission grants

A WRAPS concurrently developed for the Duluth Urban Area outlines additional implementation opportunities and BMPs that will lead to water quality improvements and achieving the TMDLs. Agencies, organizations, and landowners in the Duluth Urban Area Subwatershed have been implementing water quality projects in an effort to reduce pollutant loading in the watershed, and are expected to continue this effort into the future. For example, South St. Louis SWCD implements watershed projects such as large-scale stream restorations in impaired watersheds. The SWCD also offers technical and financial assistance for conservation efforts in the watershed. Potential cost share projects include bank stabilization, riparian buffers, and stormwater projects. Chester Creek, Miller Creek, and Amity Creek are all priority watershed projects identified by the SWCD. In addition, the SWCD has completed or planned the following activities to restore impaired streams:

- Planned restoration project on Mission Creek upstream of the Fond du Lac neighborhood. The project is funded by DNR and will stabilize the channel, repair and stabilize tributaries and gullies, provide trout habitat, and increase resiliency to future flooding.
- Restoration of Chester Creek on the segment that runs through Chester Park, funded by DNR through an appropriation by the Minnesota State Legislature. The project will re-align and re-stabilize the stream to reduce sediment loading, remove damaged dams that impede fish passage, provide trout habitat, and increase resilience to future flooding. Construction to begin in October 2017.
- Restoration of Miller Creek between Haines Road and Hwy 53, funded by the Clean Water Fund in 2015.

- Installation of a demonstration stormwater BMP at Lake Superior College within the Miller Creek Watershed, funded by the Clean Water Fund in 2015.
- Miller Hill Mall Stormwater Management Plan, funded by the Clean Water Fund in 2014.

The following projects were also recently completed on impaired streams in the Duluth Urban Area:

- The Lakeside Neighborhood Stormwater Runoff Reduction Project was completed by a team of local homeowners, experts from UMD, city utility staff, and environmental engineers from 2008 through 2011 in order to determine the best ways to reduce stormwater runoff from the project neighborhood to Amity Creek. The effort was funded through the Weber Stream Restoration Initiative.
- A restoration and erosion control project on private property along Keene Creek - South St. Louis SWCD provided technical assistance for the property owner to re-stabilize slopes, plant native species, and install a retaining wall in 2013.
- Evergreen planting effort along Amity Creek on farmland owned by UMD in 2012. In total, 250 evergreens were planted to help reduce runoff and cool water temperatures. The project was funded by the Great Lakes Restoration Initiative.
- The Duluth Stream Corps, a Civilian Conservation Corps (CCC) style program supported by Community Action Duluth, planted 7,000 trees near interstate 35 on Kingsbury Creek. A total of 18,155 trees and shrubs were planted in 2011-12 on private and public properties throughout the urban area.

7. Monitoring Plan

Monitoring is important for several reasons including:

- Evaluating water bodies to determine if they are meeting water quality standards and tracking trends;
- Assessing potential sources of pollutants;
- Determining the effectiveness of implementation activities in the watershed; and
- Delisting of waters that are no longer impaired.

Monitoring is also a critical component of an adaptive management approach and can be used to help determine when a change in management is needed. The St. Louis River Watershed began intensive watershed monitoring again in 2019, and the Lake Superior South Watershed is scheduled for intensive watershed monitoring again in 2021 as part of the MPCA's Watershed Approach. Monitoring is needed throughout the watershed to refine modeling and source assessments. Data gaps have been identified as part of the TMDL and associated modeling work. This section describes recommended monitoring activities in the watershed, subject to availability of resources and other priorities.

7.1 Total Suspended Solids

Further monitoring and evaluation of TSS sources are needed to target restoration activities. Monitoring activities could include stream assessments, monitoring of erosional processes, and storm sewer inlet monitoring to impaired streams (flow and water quality).

Monitoring activities could include:

- inspection of MS4 conveyance systems and downstream channels in the context of the identified impairments;
- inspection, study, and research in impaired watersheds to determine sources, stream characteristics and other information; and
- monitoring studies at key locations to further determine pollutant sources.

TSS samples are needed throughout the impaired watersheds to further assess potential sources and focus implementation activities. In addition, the following stream-specific monitoring recommendation are provided:

- Kingsbury Creek
  - Increase sampling under mid-range to very low flow conditions. Only one sample was collected under low and very low flows prior to this report.
  - Increase monitoring during the summer. Three samples have been taken in July, August, and September over last 10 years.
- Amity Creek
  - Increase sampling under low and very low flow conditions, especially during winter conditions. Currently no sampling under very low flows has been performed.
- Lester River
  - Increase sampling under very low flow conditions, especially during winter conditions. Currently only one sample under very low flows has been collected.

7.2 *E. coli*

E. coli samples are needed throughout the impaired watersheds to further assess potential sources and focus implementation activities. MST could be used to further evaluate sources of *E. coli* and target restoration activities. In 2020, the City of Duluth began a monitoring study to assess sources of *E. coli* to Keene Creek and Tischer Creek. MST is a component of this work.

Longitudinal, or synoptic, sampling can be done to identify hotspots along an impaired segment where higher concentrations of *E. coli* are found. This information, paired with sanitary sewer surveys and field reconnaissance, can be used to further investigate sources of *E. coli*.

Further investigations into leaky wastewater and failing septic systems through inspections and monitoring are also needed. In addition, the following stream-specific monitoring recommendations are provided:

- Keene Creek

- New monitoring effort at existing stations S003-504 and S007-323 (currently only physical stream data) to determine source areas upstream and downstream of Morris Thomas Road.
- Increase spring monitoring. In the past, three or fewer samples per month have been performed during the months of March through May.

- Miller Creek
  - New monitoring effort to determine if industrial stormwater (impervious surface) discharges from Miller Hill Mall (MN0056979) and Walmart (MN0060372) contribute to *E. coli* impairment.
  - Increase spring monitoring. In the past, three or fewer samples per month have been performed during the months of March through May.
- Sargent Creek
  - Increase sampling under very high and very low flow conditions. No sampling has been performed under very high flows and one sample under very low flows.
  - Monitor upstream of impaired segment to determine potential source areas (currently there is only one station at the downstream end).
- Stewart Creek
  - Increase sampling under very high and very low flow conditions. Currently no sampling under very high flows and one sample under very low flows has been performed.
  - Monitor upstream of impaired segment to determine potential source areas (currently there is only one station at downstream end).
- Unnamed Creek (Merritt Creek)
  - Increase sampling under mid-range and very low flow conditions. Three and two samples collected, respectively.
  - Increase spring monitoring in the past, three or fewer samples per month have been performed during the months of March through May.
- Tischer Creek
  - Monitor upstream of impaired segment and at downstream end of impaired segment to determine potential source areas (currently there is only one station at upstream end of impaired segment).
  - Increase sampling under very low flow conditions (currently only two total samples have been taken).
- Chester Creek
  - Monitor upstream of impaired segment and at downstream end of impaired segment to determine potential source areas (currently only one station at upstream end of impaired segment).

- Increase sampling under very low flow conditions (currently only two total samples have been taken).

7.3 Flow

Streamflow is a critical element to determining compliance with TMDLs and understanding the pollutant loading occurring in the watershed. Continued collection of continuous flow monitoring is needed for sites throughout the watershed; the WRAPS monitoring effort that was conducted in 2015 and 2016 should be continued to the extent possible. In addition, expanded flow monitoring to more tributaries and during winter time periods is needed to improve hydrologic modeling in the watershed, which will in turn, improve estimates of pollutant loading.

8. Implementation Strategy Summary

Implementing activities that will result in meeting the TMDLs will require careful planning and support. A watershed-based approach is recommended that is based on an overall watershed plan that addresses all impaired waters, as well as protection activities and includes prioritization, selection of the most beneficial projects, and public involvement, such as a 1W1P. 1W1P activities started in the Duluth area in 2020. The accompanying WRAPS document will serve to provide a foundation for the 1W1P. Post-project monitoring and adaptive management are both important components of successful implementation.

8.1 Permitted Sources

8.1.1 Construction Stormwater

The WLA for stormwater discharges from sites where there is construction activity reflects the number of construction sites greater than one acre expected to be active in the watershed at any one time, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local construction stormwater requirements must also be met.

8.1.2 Industrial Stormwater – General Permit

There are two existing industrial stormwater facilities the in TSS-impaired watersheds: Equipment Rental Co (MNR053D22) and Hartel's/DBJ Disposal Companies (MNRNE38MW). The WLA for stormwater discharges from sites where there is industrial activity reflects the number of sites in the watershed for which NPDES/SDS industrial stormwater permit coverage is required, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern (i.e., TSS). The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the State's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000*)*, or NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local stormwater management requirements must also be met.

8.1.3 MS4

There are nine regulated MS4s in the impaired watersheds for which NPDES/SDS Municipal Separate Storm Sewer Systems General Permit (MNR040000) coverage is required: Duluth, Hermantown, Midway Township, Proctor, Rice Lake, UMD, Lake Superior College, St. Louis County (roads), and MnDOT Outstate District (roads). Implementation strategies that can be used to meet WLAs include education and outreach, stormwater BMPs to reduce TSS and *E. coli* loading, pet waste management programs, and disconnecting impervious areas. MS4 permittees are required to document progress towards meeting the WLA(s) as part of their MS4 Stormwater Pollution Prevention Program. The MPCA Stormwater Program has provided the following clarification with regard to the TSS TMDLs:

MS4s can evaluate compliance status for the Duluth Urban Area TSS TMDLs via monitoring, modeling, or other means approved by MPCA Stormwater Program staff, with a target TSS reduction of 60% from their MS4-regulated area.

In addition, the MPCA Phase 2 MS4 permit utilizes a performance based approach to bacteria impairments, focusing on an inventory of potential bacteria sources. The MPCA is working with a diverse stakeholder group to better understand sources of bacteria in urban settings and develop appropriate guidance and tools for addressing bacteria impairments. Those tools will be available when the MS4 permit is reissued in November 2020 and will be updated as more research is conducted and as this stakeholder group proceeds with recommendations.

8.1.4 Individual Industrial Stormwater Permit

One permitted facility (Wisconsin Central Ltd., a subsidiary of Canadian National Railway) [MN0000361]) has an individual WLA for industrial stormwater runoff. Successful implementation of the following actions will demonstrate consistency with the TMDL’s assumptions and requirements with respect to Wisconsin Central Ltd.’s WLA:

- Compliance with the NPDES/SDS permit’s 30 mg/L TSS effluent limitations;
- Improved snow removal management in order to reduce the amount of sediment that reaches water bodies; and
- Reduced streambank erosion along Kingsbury Creek as it flows along the Wisconsin Central Ltd. Site.

Future NPDES/SDS permits for the facility will contain BMP implementation requirements consistent with the assumptions and requirements of the WLA.

8.2 Nonpermitted Sources

Nonpoint sources include unregulated stormwater runoff, channel erosion, failing septic systems and other sources of untreated wastewater, pets, and wildlife. A balanced approach will be needed that will include both longer-term/larger-scale and shorter-term/smaller-scale implementation activities. Implementation strategies for nonpermitted sources are summarized below. More detail on implementation and stream specific BMPs can be found in the Duluth Urban Area WRAPS document.

8.2.1 Strategies to address sources of *E. coli* in impaired streams

- **Stormwater management and disconnected imperviousness**

  Provide water quality treatment and runoff reduction using green infrastructure and other stormwater BMPs. Include volume control when applicable (i.e. when soils, topography, and depth to restrictive layer allow), and increase the level of impervious surface disconnection using ordinances and land use planning strategies. BMPs that remove sediment can also be used to reduce *E. coli,* such as enhanced street sweeping and filtration basins. Stormwater BMP guidance can be found in the MPCA's Stormwater Manual.

- **Improvements to septic systems**

  Inventory and upgrade septic systems to eliminate sources of untreated wastewater. Identify opportunities to connect to regional wastewater treatment facilities. Increase awareness and education related to septic system maintenance, particularly in urban areas.

- **Upgrade leaky wastewater infrastructure in urban areas**

  Identify and correct failing wastewater infrastructure, such as sanitary sewer inflow and infiltration, to eliminate sources of untreated wastewater. Consider potential to do so simultaneously with road replacement projects.

- **Expand access to restroom facilities in parks and public spaces**

  Identify opportunities to increase access to restroom, diaper-changing facilities, showers, and hand washing facilities in public spaces. Work with neighborhood organizations and other entities to address challenges such as vandalism. Also include signage for healthy bathing at access points along streams.

- **Trash management**

  Increase the number of trash cans along trails, at boat launches, in parks, and in neighborhoods. Consider adopt-a-road programs to encourage trash pick-up along roadways.

- **Pet waste management**

  Enhance existing pet waste management programs to ensure compliance and enforcement as needed. Consider if additional pet waste disposal stations (e.g., Mutt Mitts) and trash cans can be added and increase education through city newsletters and other outreach activities. The City of Duluth has an animal litter ordinance in place that requires “cleaning up any feces of the animal and disposing of such feces in a sanitary manner.” An effort also began in 2019 to increase awareness of pet waste issues throughout the area.

- **Wildlife waste management**

  Create or maintain programs for the management of excessive deer, beaver, and raccoon populations. Educate the public to discourage feeding of wildlife in the watershed. Consider adding or increasing buffers of vegetation surrounding open water (e.g., ponds, stream) to discourage geese, ducks, and other birds from access. Increase the number of trash receptacles in areas frequented by the public and ensure adequate trash removal.

8.2.2 Strategies to address sources of sediment in impaired streams

- **Stream restoration and bank stabilization**

  Continue to implement restoration activities to address eroding banks and areas of instability in stream channels. Focus activities in priority areas as defined in stream-specific assessments (e.g., Amity Creek Stressor Identification, see Appendix B). Address channelized segments of Kingsbury Creek through natural stream re-meanders and restoration activities. Reconnect floodplains and incorporate natural channel design when possible.

- **Buffer installation**

  Preserve the natural vegetation along stream corridors. Buffers can mitigate pollutant loading associated with human disturbances and help to stabilize streambanks and improve infiltration. Minnesota’s buffer law requires establishment of up to 50 feet of perennial vegetation along many public rivers, streams, and ditches. It is anticipated that SWCDs will work with landowners to establish and maintain required buffers. Additional value could be added by working with landowners and residents to also install fencing or stream crossings to limit access to streams, and by ensuring enforcement of Minnesota’s Shoreland Management Act.

- **Conservation and protection**

  The Duluth Natural Areas Program offers permanent protection for areas with unique ecological and water resource value. Portions of the Amity Creek system and other impaired streams may be good candidates for this protection program.

- **Stormwater management and disconnected imperviousness**

  Provide water quality treatment and runoff reduction using green infrastructure and other stormwater BMPs. Include volume control when applicable (i.e., when soils, topography, and depth to restrictive layer allow), and increase the level of impervious surface disconnection using ordinances and land use planning strategies. Identify priority areas for retrofitting of stormwater practices in untreated areas; implement BMPs that provide water quality treatment and reduce peak flows. Example stormwater BMPs could include sediment trap structures, enhanced street sweeping, ditch checks, and filtration basins. Stormwater BMP guidance can be found in the MPCA's Stormwater Manual. Ensure new developments address sediment reduction needs and mitigate flows that could potentially contribute to stream flashiness. Review and update ordinances as needed.

The Duluth Urban Area WRAPS Report outlines additional implementation opportunities and BMPs that will lead to water quality improvements and achieving the TMDLs.

8.3 Costs

TMDLs are required to include an overall approximation of implementation costs (Minn. Stat. 2007, § 114D.25). The costs to implement the activities outlined in the strategy are approximately $108 to $168 million dollars over the next 30 years. This includes the cost of increasing local capacity to oversee implementation in the watershed, as well as planning and capital costs. Assumptions that support the cost estimate are provided below.

8.3.1 TSS Costs

Implementation activities to address sediment in impaired streams include stream restoration and stormwater management. Cost assumptions are described below.

STREAM RESTORATION

Jennings et al. 2017 (see Appendix B) estimated a cost of $7 to $9 million dollars to implement stream restoration projects along Amity Creek and East Branch Amity Creek to achieve significant TSS reductions that will lead to meeting water quality standards. A similar cost estimate is assumed for Kingsbury Creek and Lester River stream improvements.

STORMWATER MANAGEMENT

Stormwater management activities that address sediment include:

- Increase frequency of sweeping to monthly or semi-monthly, with use of a regenerative air vacuum sweeper. Costs of increased frequency of street sweeping is estimated at $1 million capital costs every 10 years and $250,000 annually over the 30-year plan. Expected TSS reductions are approximately 15% to 25% as a result of this activity.
- Structural stormwater BMPs include ditch checks/sediment traps along rural section roads, enhanced vegetation of roadside ditches, sediment traps in catch basins, and stormwater basins. A cost benefit of $48,419 to $72,630 per ton of TSS removed was derived from The Nature Conservancy (2019) assuming plus or minus 20% of the high cost range for bioretention. A total cost of $34 to $51 million includes capital and maintenance costs over the life expectancy of the BMP.

8.3.2 *E. coli* Costs

Cost assumptions associated with implementation activities that address *E. coli* include:

- Upgrade/replace septic systems - $1 million to $2 million. Costs assume that all systems deemed an ITPHS are removed, upgraded, or replaced at a cost of approximately $15,000 per system. Costs do not include programmatic activities or the costs of inspection (see local capacity costs below).
- Leaky wastewater - Detailed capital costs to address leaky wastewater infrastructure are not included since the status of wastewater infrastructure is unknown and this time, however an annual cost of $1 million to $2 million has been provided to continue investigations and make repairs.
- New/expanded bathroom facilities in parks and along trails - Assume $3 million to $5 million in capital costs plus $100,000 per year for maintenance.
- Stormwater management – Street sweeping costs are included in Section 8.3.1.

8.3.3 Local Capacity Cost Calculation

Additional local staffing is needed to lead TMDL implementation. Increased staffing levels are estimated to be $200,000 to $300,000 per year. Roles and responsibilities of staffing could include developing and implementing programs aimed largely at pet waste, education and outreach, wildlife management, and septic systems.

8.4 Adaptive Management

This list of implementation elements in the more detailed WRAPS report prepared concurrently with this TMDL assessment focuses on adaptive management (Figure 80). Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL. Management activities will be changed or refined over time to efficiently meet the TMDL and lay the groundwork for de-listing the impaired water bodies.

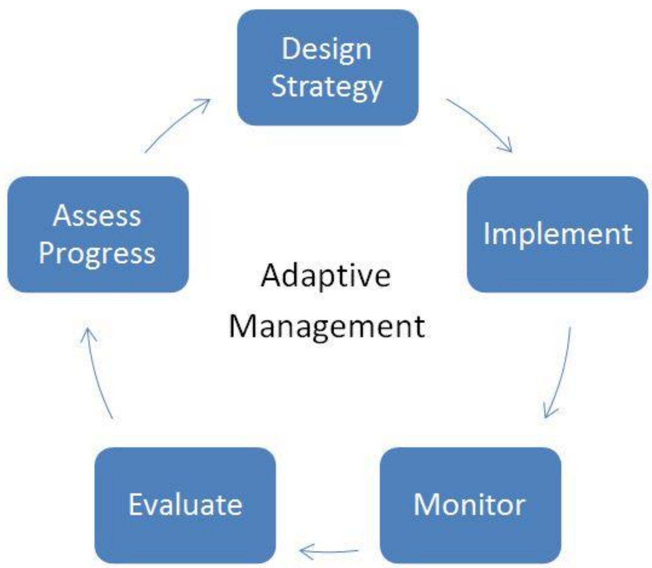


Figure 80. Adaptive management process.

Natural resource management involves a temporal sequence of decisions (or implementation actions), in which the best action at each decision point depends on the state of the managed system (Williams et al. 2009). As a structured iterative implementation process, adaptive management offers the flexibility for responsible parties to monitor implementation actions, determine the success of such actions, and ultimately, base management decisions upon the measured results of completed implementation actions and the current state of the system. This process enhances the understanding and estimation of predicted outcomes, and ensures refinement of necessary activities to better guarantee desirable results. In this way, understanding of the resource can be enhanced over time, and management can be improved (Williams et al. 2009).

9. Public Participation

A series of stakeholder meetings were held to obtain input on TMDL development with both the Core Team and the DUWAC. Organizations included in the Core Team include:

- City of Duluth
- Fond du Lac Band of Lake Superior Chippewa
- Minnesota Board of Soil and Water Resources
- Minnesota Department of Agriculture
- Minnesota Department of Health
- DNR
- MnDOT
- MPCA
- South St. Louis SWCD
- University of Minnesota – Duluth, Natural Resources Research Institute and Facilities Management
- University of Minnesota Sea Grant Program
- Lake Superior College
- DUWAC members

DUWAC members include several local governments: City of Duluth, City of Hermantown, City of Proctor, Midway Township, Thomson Township, Normanna Township, Gnesen Township, Lakewood Township, and St. Louis County.

Meetings were held on the following dates:

- **January 24, 2017**

  This Core Team meeting kicked off TMDL and WRAPS development and introduced the process.

- **April 3, 2017**

  This Core Team meeting focused on pollutant source assessment, TMDLs, and needed reductions.

- **June 13, 2017**

  This Core Team meeting focused on the TMDL source assessment and an approach for future beach TMDLs. For the second half of the meeting, attendees were broken into small groups to provide input on priorities and issues in the watershed including source identification and potential implementation practices.

- **June 22, 2017**

  This meeting of the DUWAC consisted of a group exercise that allowed noncore team stakeholders to provide input on priorities and issues within the watershed and potential implementation activities.

- **October 26, 2017**

  This meeting included an overview of the TMDL content, an overview of the MS4 permit program, and information on a stream geomorphic assessment for Amity Creek. Members of the Core Team, DUWAC, RSPT, regulated MS4s, and others participated.

- **March – June 2018**

  The draft TMDL was first public noticed from March 19 to April 18, 2018 and then extended April 19 to June 18 2018. In response to public comment received during this time, the MPCA reevaluated the draft TMDL and made significant updates reflected in the June 2020 edition.

- **May 22, 2019**

  Approaches to develop revised allocations were presented and discussed with regulated MS4s and others. Discussion also focused on the approach to address comments received during the first public comment period.

- **July 24, 2019**

  Updated source assessments were presented and discussed including updated sediment loading models with regulated MS4s and others.

- **December 12, 2019**

  Updated TMDL allocations were discussed with regulated MS4s and other stakeholders.

- **June 22, 2020 through July 22, 2020**

  Public comment period on updated TMDL report.

Public Notice for Comments

An opportunity for public comment on the revised draft TMDL report was provided via a public notice in the *State Register* from June 22, 2020 through July 22, 2020. There were 10 comments received and responded to as a result of the notice. Staff from several state agencies and Duluth residents provided responses to the draft TMDL. Staff of one non-profit organization also provided comment. One inquiry was received from an engineering firm. And one inquiry was received from a College of St. Scholastica instructor. Roughly half of the comments or inquiries described BMP efforts or more efforts to engage in stream health activities. A few comments were specific to elements of the TMDL or the TMDL program interface with stormwater permits. Two edits were made to the TMDL text as a result of comments provided, one to incorporate a statement about drinking water benefits in the executive summary and a second to the MS4 implementation section 8.1.3, noting the changes being made to the MS4 permit for managing bacteria and the ongoing stakeholder effort to continue to dialog about MS4 issues and urban bacteria management.

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Appendix A – HSPF Model Report

See Separate Document.

Appendix B – Amity Creek Stressor Identification

Amity Creek Stressor Identification

Prepared for:

South St. Louis Soil and Water Conservation District
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EXECUTIVE SUMMARY

Amity Creek is a small coldwater trout stream on the Northeast edge of Duluth, Minnesota. The stream is recognized as one of the highest quality trout fisheries and is a popular recreational area in the City of Duluth. However, increasing development pressure and water quality impairments are limiting the stream's potential use by area residents. Amity Creek (main stem) is listed on the 2004 Impaired Waters List for aquatic life due to turbidity, while East Branch Amity Creek is listed on the Draft 2014 Impaired Waters List for aquatic life due to turbidity. Recent watershed efforts by local agencies have focused on outreach, tree planting, hydrology, trail impacts, and bluff stabilization. It is well understood that negative effects of bank erosion are impacting the watershed but there has been little work to date to map and diagnose the magnitude of such impacts.

This project provides a geomorphic assessment of the entire Amity Creek, focusing on the physical conditions and stability of the system. The 16.7-square-mile Amity Creek watershed was studied to determine high-priority sediment loading sources and potential restoration projects. Several stream reaches were found to be rapidly adjusting through channel evolution processes associated with incision, entrenchment, and meander migration. Streambank erosion is estimated to be greater than 16,000 tons per year for the 33.5 miles of main stem and tributary streams. About two-thirds of the total streambank erosion is occurring along four main stem stream reaches totaling about 5 miles in length as listed below.

1. Reach AM-7 (main stem of Amity Creek between Bridges #6 and #7 on Seven Bridges Road): 1,892 linear feet of stream with 11 % of total erosion

2. Reach AM-9 (main stem Amity Creek between the East Branch confluence and Hawk Ridge Road): 4,417 linear feet of stream with 21 % of total erosion

3. Reach EB-1 (East Branch Amity Creek between Jean Duluth Rd and main stem confluence): 9,409 linear feet of stream with 17 % of total erosion

4. Reach EB-2 (East Branch Amity Creek between Riley Road and Jean Duluth Road): 8,347 linear feet of stream with 15 % of total erosion

Recommended restoration project concepts are outlined for these four stream reaches to create stable geomorphic conditions to support sustainable water quality and biology in the watershed. Expected costs for these restoration projects range from $250 to $500 per linear foot with the total estimated cost for restoration of these high-priority reaches in the range of $7M to $9M. Investment in restoration projects like these will most likely be necessary to remove these streams from the list of impaired waters, will increase the resiliency of the stream channel and biological community, and will ultimately improve water quality in Lake Superior, the largest source of fresh surface water in North America. As local agencies prepare for the competitive process of requesting funds and resources through MN DNR and MN Board of Water and Soil Resources for implementation of water quality restoration and protection projects, this project will ensure that the partners of MPCA are well-positioned to implement landscape level projects.

INTRODUCTION

The Amity Creek watershed consists of 16.7 square miles located on the Eastern edge of the City of Duluth, St. Louis County, Minnesota. The watershed is in EPA Level IV Ecoregion 50t, North Shore Highlands (ftp://newftp.epa.gov/EPADataCommons/ORD/Ecoregions/us/Eco_Level_IV_US.pdf). Amity Creek is a biologically healthy cold water stream (trout stream) with two main branches and tributaries totaling 33.5 miles of stream length. Amity Creek (main stem) is listed on the 2004 Impaired Waters List for aquatic life due to turbidity. The East Branch Amity is listed on the Draft 2014 Impaired Waters List for aquatic life due to turbidity.

Sedimentation due to stream channel instability and bank erosion are leading causes of water quality impairment. The specific locations and relative magnitudes of sediment loading have not been previously documented. This project report describes a sediment stressor assessment of the watershed including map delineations and categorizations of sediment sources along with suggested restoration projects. Efforts to improve stream health and enhance habitat should apply the five components of watershed health (hydrology, geomorphology, connectivity, water quality, and biology) as a framework for setting goals and objectives.

The Amity Creek watershed delineation from USGS StreamStats is shown in Figure 1. The watershed is 71% forested, 19% grassland, 3% wetlands, 2% shrubs, 2% rural and urban development, and 1% open water.

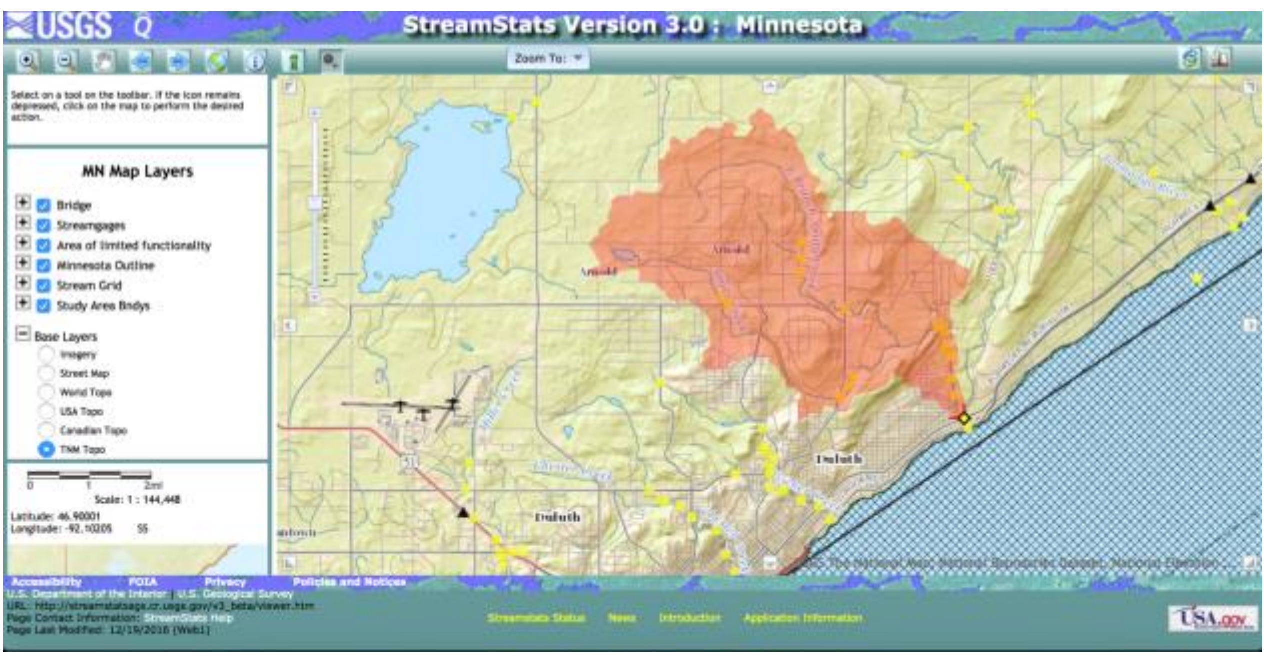

Figure 1. Amity Creek Watershed Delineated by USGS StreamStats (streamstatsags.cr.usgs.gov).

The Amity Creek watershed is mostly rural with a land use history of timber logging and some agriculture. Changes in hydrology associated with land clearing have resulted in increased peak stream flows and sediment transport competence and capacity. Streambank erosion, channel incision, and hillslope erosion are evident in many locations in the watershed. Many stream reaches are actively adjusting toward new equilibrium conditions associated with altered watershed boundary conditions and forcing functions.

METHODS

This watershed assessment project included desktop and field data collection, development of a stream sediment matrix, and conceptual planning for restoration projects on high-priority stream reaches. Desktop analysis with GIS was used to delineate the 68 stream reaches shown in Figure 2 and identify stream types (Rosgen, 1994). These reaches are defined by starting and ending points, stream types, and lengths in Table 1 (19 Amity Creek reaches and 7 East Branch Amity Creek reaches) and Table 2 (42 tributary reaches).

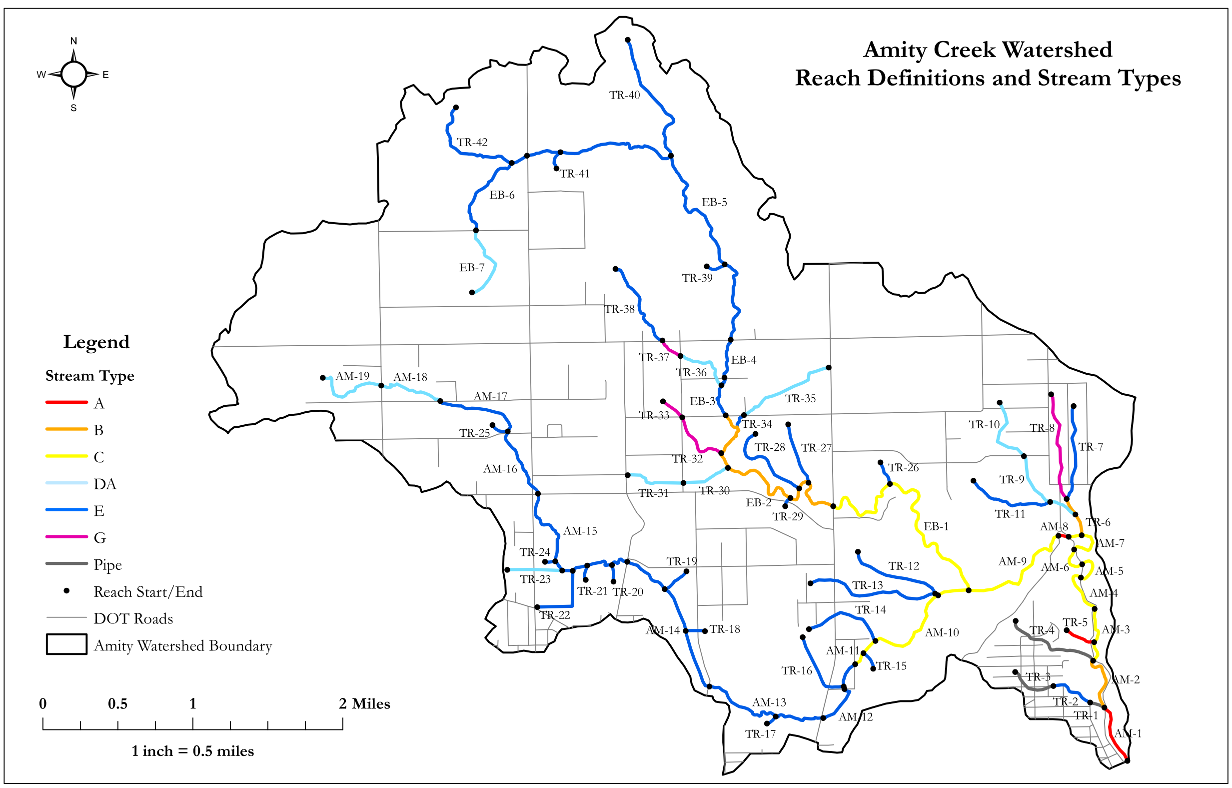

Figure 2. Amity Creek Watershed Reach Definitions and Rosgen Stream Types.

Table 1. Reach Definitions with Rosgen Stream Types and Reach Lengths for Mainstems of Amity Creek and East Branch Amity Creek.

Reach	Start	End	Rosgen Type	Length (ft)
AM-1	Bridge 1	Lester River	A1	2,157
AM-2	Bridge 2	Bridge 1	B3	2,233
AM-3	Bridge 3	Bridge 2	C3b	1,935
AM-4	Bridge 4	Bridge 3	C3b	1,744
AM-5	Bridge 5	Bridge 4	C4b	1,214
AM-6	Bridge 6	Bridge 5	C4	1,042
AM-7	Bridge 7	Bridge 6	C4	1,892
AM-8	Bridge 8	Bridge 7	A1	370
AM-9	Confluence w/ East Br	Bridge 8	C4	4,417
AM-10	Colby Ave	Confluence w/ East Br	C4/E4	5,636
AM-11	Amity St	Colby Ave	E4	1,032
AM-12	Jean Duluth Rd	Amity St	E4	1,596
AM-13	Vermilion Rd	Jean Duluth Rd	E3	4,830
AM-14	Woodland Ave	Vermilion Rd	E5	5,600
AM-15	Martin Rd	Woodland Ave	E3	6,033
AM-16	Fairview Rd	Martin Rd	E4	2,650
AM-17	Nelson Rd	Fairview Rd	E5	2,994
AM-18	Howard Gnesen Rd	Nelson Rd	DA5	2,795
AM-19	Mud Lake	Howard Gnesen Rd	DA5	2,397
EB-1	Jean Duluth Rd	Amity Creek	C4/B4	9,409
EB-2	Riley Rd	Jean Duluth Rd	B4/F4	8,347
EB-3	Cooper Rd	Riley Rd	E5	1,568
EB-4	W Tischer Rd	Cooper Rd	E5	1,452
EB-5	Arnold Rd	W Tischer Rd	E4	13,746
EB-6	Fiskett Rd	Arnold Rd	E4	3,878
EB-7	Origin	Fiskett Rd	DA4	2,891

Table 2. Reach Definitions with Rosgen Stream Types and Reach Lengths for Tributaries.

Reach	Start	End	Type	Length (ft)
TR-1	N 58th Ave E	Amity Creek	Pipe	532
TR-2	Glendale St	N 58th Ave E	E4	1,557
TR-3	Origin	Glendale St	Pipe	1,666
TR-4	Origin	Amity Creek	Pipe	3,395
TR-5	Origin	Amity Creek	A3	1,088
TR-6	Confluence of TR-7 and TR-8	Amity Creek	B3	1,444
TR-7	Origin	Confluence w/ TR-6	E3	3,418
TR-8	Origin	Confluence w/ TR-6	G4	3,910
TR-9	Medin Rd	Confluence w/ TR-6	DA5	2,998
TR-10	Origin	Medin Rd	DA5	2,636
TR-11	Origin	Confluence w/ TR-9	E4	3,078
TR-12	Origin	Amity Creek	E4	3,319
TR-13	Origin	Amity Creek	E4	4,901
TR-14	Origin	Amity Creek	E4	2,972
TR-15	Origin	Amity Creek	E4	679
TR-16	Origin	Amity Creek	E4	2,558
TR-17	Origin	Amity Creek	E4	407
TR-18	Origin	Amity Creek	E4	677
TR-19	Origin	Amity Creek	E4	1,004
TR-20	Origin	Amity Creek	E4	583
TR-21	Origin	Amity Creek	E4	531
TR-22	Origin	Amity Creek	E4	2,477
TR-23	Origin	Amity Creek	DA5	1,941
TR-24	Origin	Amity Creek	E5	362
TR-25	Origin	Amity Creek	E5	623
TR-26	Origin	East Br	E4	858
TR-27	Origin	East Br	E4	2,203
TR-28	Origin	East Br	E4	3,346
TR-29	Origin	East Br	E4	356
TR-30	Eagle Lake Rd	East Br	DA5	1,710
TR-31	Origin	Eagle Lake Rd	DA5	2,118
TR-32	Riley Rd	East Br	G4	2,232
TR-33	Origin	Riley Rd	G4	877
TR-34	Riley Rd	East Br	E4	547
TR-35	Origin	Riley Rd	DA4	3,604
TR-36	Eagle Lake Rd	East Br	DA5	2,087
TR-37	W. Tischer Rd	Eagle Lake Rd	G4	874
TR-38	Origin	W. Tischer Rd	E4	3,353
TR-39	Origin	East Br	E4	715
TR-40	Origin	East Br	E4	4,899
TR-41	Origin	East Br	E4	673
TR-42	Origin	East Br	E4	3,913

An initial field walk in October, 2015, was used to verify stream reach boundaries and stream types. During this stream walk, stream reach conditions were evaluated using the two-page Auburn University Stream Condition Rapid Assessment worksheet (Brantley, 2016) shown in Figure 4. This rapid assessment worksheet was developed in cooperation with EPA Region 4 to support watershed assessment and stream restoration planning. The worksheet includes several important geomorphic parameters in addition to ecological factors including vegetation and habitats.

The first section of the Rapid Assessment worksheet includes basic geomorphic parameters that indicate stream equilibrium status. The width/depth ratio (WDR), bank height ratio (BHR), and entrenchment ratio (ER) are key variables for this assessment. We found several reaches with high BHR (indicating incision), low ER (indicating entrenchment), and/or high WDR (indicating meander pattern adjustment such as down-valley meander migration). These conditions are typical of unstable (or disequilibrium) stream systems that are rapidly adjusting to watershed or valley changes. The Stream Channel Succession Scenarios diagrams shown in Figure 3 can be used to understand how these stream segments are evolving toward a new state (Rosgen, 2006). For example, Scenario 1 predicts that incised and entrenched streams (Gc or F stream types) found in the Amity Creek watershed are evolving toward C and/or E stream types at a lower elevation following extensive erosion and sediment transport. The Notes section at the end of the Rapid Assessment worksheet is used to document channel evolution observations.

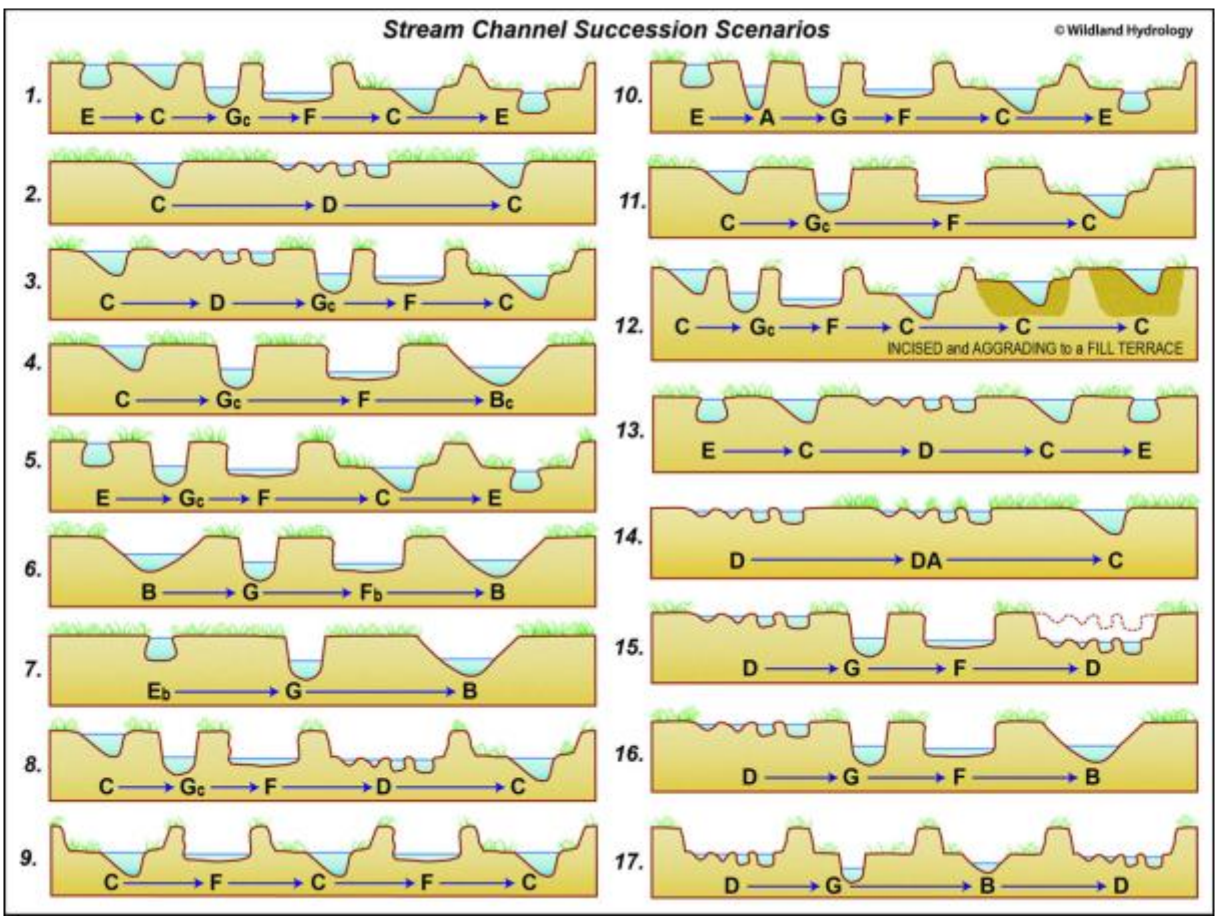

Figure 3. Stream Channel Succession Scenarios for Predicting Chanel Evolution (Rosgen, 2006).

The value of the rapid assessment worksheet is in identifying critical factors of concern that require further analysis. For each of twelve assessment parameters, each stream reach was assigned a rating of *Good*, *Fair*, or *Poor* based upon visual assessment in relation to expected stream conditions in the region. For this assessment, we were not concerned with the total score as much as identifying critical parameters of concern relevant to the sediment stressor identification objectives of this study. Each parameter is discussed below in relation to the Amity Creek study.

1. Upstream watershed impacts from stormwater, wastewater, or sediment: We focused on visible impacts of upstream stormwater causing excessive erosion or upstream sediment loading causing aggradation or habitat impacts.
2. Local stream reach impacts from ditches, pipes, livestock, utilities, or roads: We focused on stormwater outfalls and runoff from unpaved roads and trails. There were also some impacts due to horses.
3. Channel dimension related to bankfull cross-section measurements: We observed several reaches with disequilibrium indicated by channel incision, widening, and high variability in actively adjusting meanders.
4. Channel pattern related to planform measurements: We observed several reaches with disequilibrium indicated by tight bends, cutoffs, down-valley meander migration, and impacts due to previous straightening.
5. Channel bed profile related to longitudinal profile measurements: We observed several reaches with disequilibrium indicated by headcutting, plane bedform, aggradation, or riffle migration into pools.
6. Streambank stability and protection from erosion: We observed several reaches with moderate to high erodibility resulting from bare soil, eroding bends, steep banks, high banks, lack of roots, and high near-bank stress conditions.
7. Floodplain connection for bankfull flood access: We estimated bank height ratio (BHR) to rate this parameter as *Good* (BHR < 1.2), *Fair* (BHR = 1.2–1.9), or *Poor* (BHR > 2).
8. Floodplain morphology to dissipate flood energy and minimize erosion: We estimated the width of effective floodplain and identified reaches of concern where entrenchment ratios were less than 5 and/or had substantial contractions.
9. Riparian vegetation to provide shade, nutrient uptake, and food sources: We focused on natural deep-rooted buffers effective in stabilizing streambanks and supporting aquatic habitats. Several reaches were found to have impaired riparian vegetation due to adjacent land use management or location of a stream segment near an eroding hillside.
10. Habitats including diverse bedform, large woody debris, leaf packs, root hairs: We focused on important habitats identified by local biologists including deep pools, narrow fast-flowing riffles, and large woody debris.
11. Water quality and stream bed sediments: Since we conducted the assessment during a low-flow condition with very low turbidity, we focused on embeddness of riffles due to fine sediments from bank erosion and insufficient stream power in over-wide channel segments.
12. Presence of desirable fish and macroinvertebrates expected for watershed. We did not collect aquatic biota for this study

Stream Condition Rapid Assessment

Stream name & location:	Assessed by:
Ecoregion:	Site visit date:
Watershed drainage area (sq mi):	Substrate (sand, gravel, cobble, bedrock):
Stream slope (ft/ft): Bankfull riffle area (sq ft):	Stream reach length (ft): Width/depth ratio (WDR):
Entrenchment ratio (ER):	Bank height ratio (BHR):
Sinuosity (K):	Streambank stability (BEHI):

Stream Condition and Function: Score from 0 to 2 indicating natural stream integrity and health:
2 = Good; 1 = Fair; 0 = Poor

1. **Upstream watershed impacts from stormwater, wastewater, or sediment** ______

Good: no impacts from upstream sources	Fair: some minor impacts from upstream sources	Poor: major impacts from upstream sources

2. **Local stream reach impacts from ditches, pipes, livestock, utilities, or roads** ______

Good: no impacts from local sources	Fair: some minor impacts from local sources	Poor: major impacts from local sources

3. **Channel dimension related to bankfull cross-section measurements** ______

Good: natural equilibrium width, depth, and area dimensions expected for the watershed	Fair: some disequilibrium indicated by unnatural dimensions	Poor: major disequilibrium indicated by incision, widening, high variability, or channelized system

4. **Channel pattern related to planform measurements** ______

Good: natural equilibrium meander pattern with sinuosity expected for the watershed	Fair: some disequilibrium indicated by unnatural pattern features	Poor: major disequilibrium indicated by tight bends, cutoffs, rapid down-valley meander migration, or straightening

5. **Channel bed profile related to longitudinal profile measurements** ______

Good: natural equilibrium riffles, pools, steps, glides, and runs with bedform expected for the watershed	Fair: some disequilibrium indicated by unnatural or missing bedform features	Poor: major disequilibrium indicated by head cutting, plane bed, aggradation, or riffle migration into pools

6. Streambank stability and protection from erosion ______

Good: low erodibility resulting from covered soil, low banks, deep roots, low stress	Fair: moderate erodibility resulting from some bare soil or erodible bank conditions	Poor: high erodibility resulting from bare soil, eroding bends, steep banks, high banks, lack of roots, high stress

7. Floodplain connection for bankfull flood access ______

Good: regular floodplain access with BHR < 1.2	Fair: some incision with BHR = 1.2–1.9	Poor: severely incised channel with BHR > 2

8. Floodplain morphology to dissipate flood energy and minimize erosion ______

Good: low entrenchment with ER > 5 and no contractions	Fair: moderate entrenchment with ER = 1.5–5 and/or minor contractions	Poor: severe entrenchment with ER < 1.5 and/or major contractions

9. Riparian vegetation to provide shade, nutrient uptake, and food sources ______

Good: healthy native plants growing in more than 90% of 50-ft buffer on both sides	Fair: healthy native plants growing in half to 90% of 50-ft buffer on both sides	Poor: healthy native plants growing in less than half of 50-ft buffer on both sides

10. Habitats including diverse bedform, large woody debris, leaf packs, root hairs ______

Good: healthy aquatic micro- and macro-habitat features expected for watershed	Fair: lacking up to half of expected aquatic habitat features	Poor: lacking more than half of expected aquatic habitat features

11. Water quality and stream bed sediments ______

Good: clear water with natural sediments expected for watershed	Fair: some turbidity and/or embeddedness affecting habitat conditions	Poor: excessive turbidity and/or embeddededness strongly affecting habitat conditions

12. Presence of desirable fish and macroinvertebrates expected for watershed ______

Good: healthy communities including intolerant taxa	Fair: missing some intolerant taxa	Poor: lacking expected communities and/or dominated by tolerant taxa

Total Score: ____________ (< 9 Poor; 9 – 15 Fair; 16 – 21 Good; > 21 Excellent)

Notes: ____

Figure 4. Auburn University Rapid Stream Assessment Worksheet (Brantley, 2016).

RESULTS

Rapid Assessment

Results of the Rapid Assessment are presented graphically in Figure 5. The color-coded map in Figure 5 shows the assessed “level of concern” for each reach determined using the Auburn University Rapid Stream Assessment Worksheet during visual observations. Level of concern is rated as either “Low,” “Moderate,” “High,” or “Very High” based primarily on geomorphic stability as evidenced by bank erosion and channel evolution scenario. Stream reaches rated “Very High” and “High” have inherent geomorphic instabilities and severely eroding banks warranting further investigation. These reaches are likely to be major sources of sediment loading in the watershed and are strong candidates for restoration and stabilization projects to improve watershed health. Reaches rated “Moderate” have lesser erosion problems that may need to be addressed before developing into more substantial problems. Reaches rated “Low” are currently stable and should be protected from future impacts. This rapid visual assessment is valuable in targeting reaches for further evaluation and long-term monitoring.

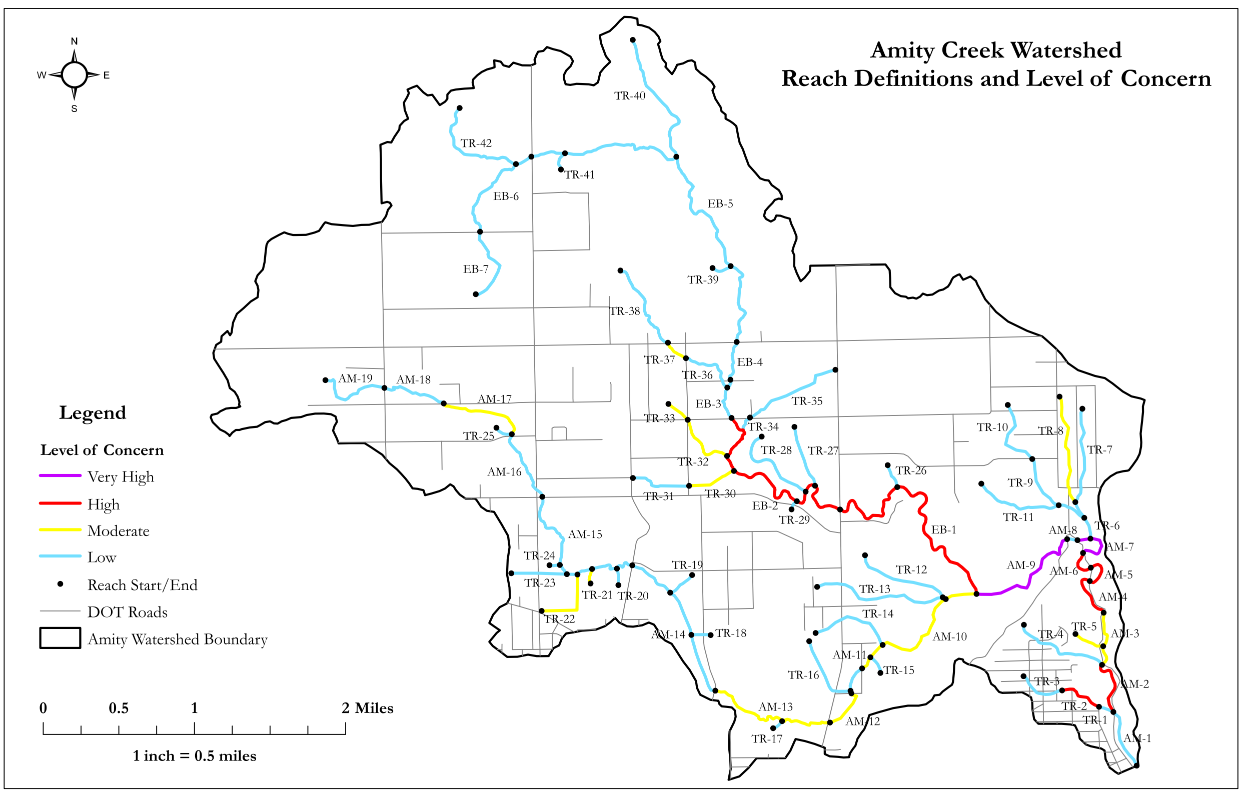

Figure 5. Amity Creek Watershed Reach Definitions and Level of Concern Determined from the Rapid Assessment.

Erosion Rate Assessment

Follow-up field assessments in May and September, 2016, were used to study high-priority reaches in more detail using field cross-section measurements and application of the Bank Assessment for Non-point source Consequences of Sediment (BANCS) assessment (Harrelson et al, 1994; Rosgen, 2006). The BANCS approach to estimate streambank erosion rate based on BEHI and NBS assessments was applied at 11 sites in the watershed to estimate relative streambank erosion rates and develop an erosion rate categorization matrix. These 11 sites were selected to represent the range of conditions observed in the Rapid Assessment. On five reaches, pairs of “unstable” and “reference” cross-sections were measured in close proximity to each other. The “reference” section was selected to represent stable riffle morphology with clear bankfull indicators to aid in identifying bankfull stage on the “unstable” section with active bank erosion.

Cross-section morphology measurement results for these 11 sites are listed in Table 3 with bankfull cross-section areas for the “reference” sections plotted on Regional Curve Relationships in Figure 7 to verify our field determination of bankfull stage. Analysis of Figure 7 shows that for drainage areas ranging from 3 to 17 square miles, the measured bankfull cross-section areas in the Amity Creek Watershed are generally aligned with previously collected data provided by the MPCA and SWCD on the Beaver River and surrounding watersheds.

Figure 6. Locations of Cross-section and BANCS Measurement Sites.

Table 3. Morphology Results for 11 Cross-sections Located as Shown in Figure 6.

XS	Reach	Drain Area (sq mi)	Bankfull Area (sq ft)	Bankfull Width (ft)	Bankfull Depth (ft)	W/d	Entrench-ment Ratio	D50 (mm)	Rosgen Type
1a	AM-10	4.7	19.8	16.4	1.2	13.6	2.7	45	C4
1b	AM-10	4.7	16.8	13.0	1.3	10.1	3.8	45	E4
2a	EB-2	7.6	32.0	28.8	1.1	25.8	1.4	60	F4
2b	EB-2	7.6	43.7	24.1	1.8	13.3	1.6	60	B4
3a	EB-5	3.5	12.4	9.0	1.4	6.5	22.2	10	E4
3b	EB-5	3.5	23.9	10.9	2.2	5.0	18.3	10	E4
4	AM-14	3.8	30.3	16.3	1.9	8.7	10.4	30	E4
5a	AM-9	13.8	64.4	34.7	1.9	18.7	3.5	60	C4
5b	AM-9	13.8	51.2	40.0	1.3	31.3	3.0	60	C4
6a	AM-2	16.2	85.2	40.0	2.1	18.8	1.5	120	B3
6b	AM-2	16.2	69.3	40.5	1.7	23.7	1.7	120	B3

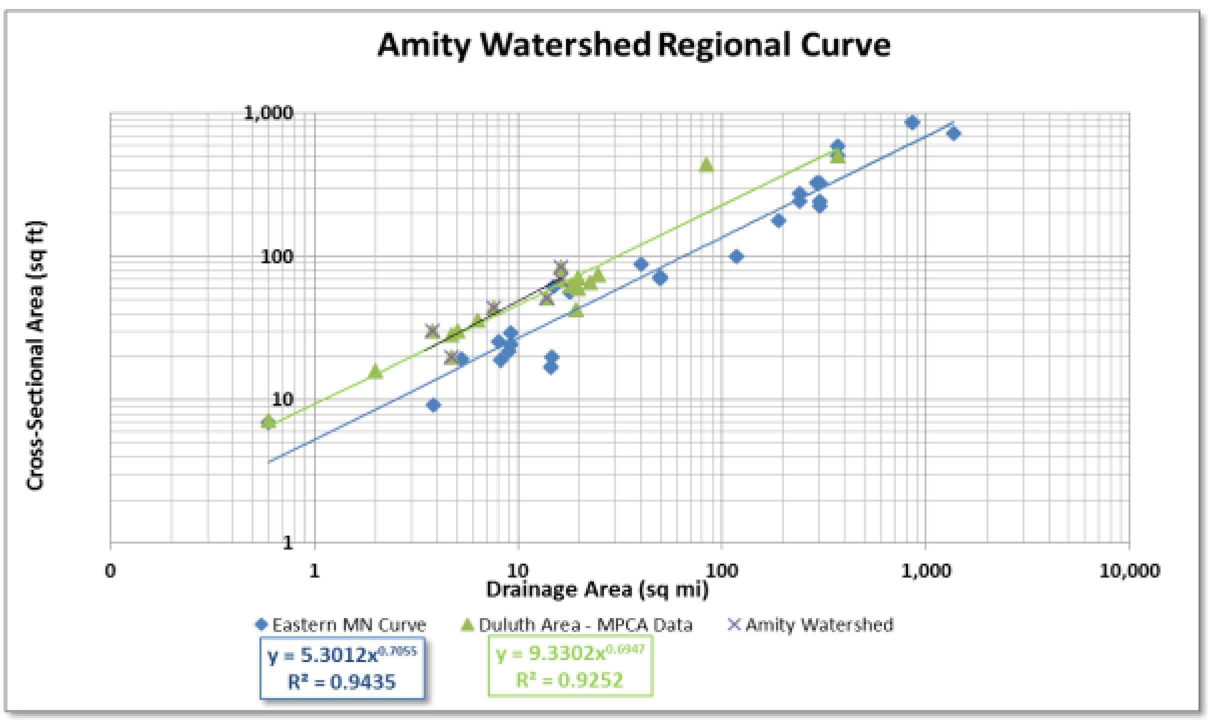

Figure 7. Bankfull Cross-Section Areas from Table 3 Plotted on Regional Curve Relationships for Eastern Minnesota and Duluth Area.

The BANCS assessment applies the Bank Erosion Hazard Index (BEHI) to determine the streambank vulnerability to erosion and Near Bank Stress (NBS) to evaluate the relative erosive energy applied to a streambank. The field-assessed BEHI factors are bank height ratio, root depth ratio, root density, bank angle, bank surface protection, and bank materials. The NBS factors include meander radius of curvature, depth of flow near the bank, and the presence of flow-directing bedforms. Each of the BEHI and NBS factors was estimated in the field at the sites shown in Figure 6 and scored on a relative scale from Low to Extreme in terms of potential bank erosion. At each BANCS assessment site, the surrounding hillslopes were also evaluated visually as potential sediment loading sources. Results of the BANCS assessments for these 11 sites are listed in Table 4.

Table 4. BANCS Assessment Summary Results for 11 Sites Located as Shown in Figure 6.

XS	Reach	Reach Level of Concern	Feature	Condition	BEHI	NBS	Erosion Category
1a	AM-10	Moderate	Riffle	Unstable	Moderate	High	4
1b	AM-10	Moderate	Riffle	Reference	Low	Moderate	2
2a	EB-2	High	Pool	Unstable	Moderate	High	5
2b	EB-2	High	Riffle	Reference	Low	Low	1
3a	EB-5	Low	Riffle	Reference	Low	Low	1
3b	EB-5	Low	Pool	Reference	Moderate	High	2
4	AM-14	Low	Riffle	Reference	Low	Low	1
5a	AM-9	Very High	Pool	Unstable	High	Very High	4
5b	AM-9	Very High	Riffle	Reference	Low	Low	1
6a	AM-2	High	Riffle	Reference	Low	Moderate	5
6b	AM-2	High	Riffle	Unstable	Moderate	Moderate	3

Based on the streambank and hillslope erosion assessments, we determined that there are six categories of erosion conditions in the Amity Creek Watershed as described in Table 5. These categories represent the range of conditions observed in the field assessments and can be used to identify critical areas for treatment to achieve sediment loading reduction objectives.

Each category is described in detail below with example photographs of reach conditions typically observed for that erosion category. The estimated streambank erosion rate for each category is indicative the relative annual lateral bank recession expected to occur on average based on measured erosion rates documented in Colorado (Rosgen, 2006). This analysis is a broad generalization of erosion rate assessments that is not expected to provide explicitly accurate determinations of sediment loading but rather is intended to support identification of high-priority stream reaches for erosion control based on easily observed key parameters listed in Table 5. Future field studies in this watershed and nearby streams may be used to refine these categories as warranted.

Table 5. Erosion Rate Categories in the Amity Creek Watershed Based on BEHI, NBS, and Hillslope Erosion Conditions.

Erosion Factor	Erosion Rate Categories (Streambank and Hillslope Sediment Sources)					
	1	2	3	4	5	6
Bank Height Ratio	< 1.2	< 1.2	< 1.5	< 1.5		
Root Depth Ratio	> 0.9	> 0.6	< 0.5	< 0.5		
Root Density	> 90%	> 60%	< 50%	< 50%		
Bank Angle	< 90 deg	< 90 deg	Variable	Variable		
Surface Protection	> 90%	> 60%	< 50%	< 50%		
Bank Materials	Cohesive	Cohesive	Toe Protection	Non-cohesive	Bedrock or Boulders	Bedrock or Boulders
BEHI Rating	Low	Moderate	Moderate to High	High to Extreme		
NBS Rating	Low to Moderate	Moderate to High	Moderate to High	Moderate to High		
Entrenchment Ratio	> 2	> 2	Variable	Variable		
Radius of Curvature Ratio	> 2	1 to 3	1 to 2	1 to 2		
Bank Vegetation	Excellent	Excellent	Poor	Poor		
Erosion Rate (ft/yr)	< 0.1	0.1 to 0.4	0.3 to 0.5	0.5 to 2.0	< 0.1	< 0.1
Hillslope Erosion Potential	Stable	Stable	Stable	Stable	Unstable	Stable

Category 1 stream reaches have very low bank erosion and stable hillslopes. These reaches have low bank height ratios, high entrenchment ratios, low to moderate gradients, meandering E or C channels with high radius of curvature ratios, excellent woody and grassy vegetation with roots at toe of slope, and no hillslope erosion. The estimated erosion rate is less than 0.1 ft/yr based on low BEHI and low to moderate NBS ratings.

Figure 8. Category 1 Erosion Rates Observed in Reaches AM-14 and EB-3 (less than 0.1 ft/yr).

Category 2 stream reaches have low to moderate bank erosion on an undercut bank and stable hillslopes. These reaches have low bank height ratios, high entrenchment ratios, low to moderate gradients, meandering E or C channels with low to moderate radius of curvature ratios, excellent woody and grassy vegetation with undercut bank typically on an outside meander bend, and no hillslope erosion. The estimated erosion rate is 0.1 to 0.4 ft/yr based on moderate BEHI and moderate to high NBS ratings.

Figure 9. Category 2 Erosion Rates Observed in Reaches EB-5 and AM-10 (0.1 to 0.4 ft/yr).

<u>Category 3</u> stream reaches have moderate erosion on exposed banks and stable hillslopes. These reaches have moderate to high bank height ratios, low to moderate entrenchment ratios, low to moderate gradients, E/C or B channels with low to moderate radius of curvature ratios, some rock toe protection, poor to non-existent woody and grassy vegetation, and no hillslope erosion. The estimated erosion rate is 0.3 to 0.5 ft/yr based on moderate to high BEHI and moderate to high NBS ratings.

Figure 10. Category 3 Erosion Rates Observed in Reaches AM-2 and EB-2 (0.3 to 0.5 ft/yr).

<u>Category 4</u> stream reaches have high erosion on exposed banks and stable hillslopes. These reaches have moderate to high bank height ratios, low to moderate entrenchment ratios, low to moderate gradients, E/C or B channels with low to moderate radius of curvature ratios, no toe protection, poor to non-existent woody and grassy vegetation, and no hillslope erosion. The estimated erosion rate is 0.5 to 2.0 ft/yr based on high to extreme BEHI and moderate to high NBS ratings.

Figure 11. Category 4 Erosion Rates Observed in Reaches AM-9 and AM-10 (0.5 to 2.0 ft/yr).

Category 5 stream reaches have very low bank erosion and unstable eroding hillslopes. These reaches have bedrock or boulders along the banks below bankfull stage streambank erosion. It is not possible to predict hillslope erosion rates for these reaches due to the complex geotechnical erosion processes and variability in slopes and soil composition.


Figure 12. Category 5 Erosion Rates Observed in Reaches AM-3 and AM-2 (less than 0.1 ft/yr streambank erosion and variable hillslope erosion rates).

Category 6 stream reaches have very low bank erosion and stable hillslopes. These reaches are canyons with bedrock walls and vegetated hillslopes.


Figure 13. Category 6 Erosion Rates Observed in Reaches AM-1 and AM-8 (less than 0.1 ft/yr streambank erosion and no hillslope erosion).

Streambank Sediment Matrix

Each of the 68 reaches was assigned a dominant Streambank Erosion Rate Category from Table 5 based on the typical observed condition of the streambanks and the immediate potential for downstream sediment contributions. The expected lateral erosion rate was multiplied by the typical bank height and the reach length in order to estimate relative sediment loading in tons per year as listed in Table 6.

Table 6. Relative Streambank Erosion Rates for Amity Creek Watershed Reaches.

Reach	Concern	Category	L (ft)	Ht (ft)	ft/yr	ton/yr	%
AM-1	LOW	6	2,157	4	0.1	43	0.3
AM-2	HIGH	3	2,233	6	1	670	4.0
AM-3	MOD	2	1,935	5	0.4	193	1.2
AM-4	HIGH	3	1,744	6	1	523	3.1
AM-5	HIGH	3	1,214	6	1	364	2.2
AM-6	HIGH	3	1,042	6	1	313	1.9
AM-7	VERY HI	4	1,892	10	2	1,892	11.4
AM-8	LOW	6	370	4	0.1	7	0.0
AM-9	VERY HI	4	4,417	8	2	3,534	21.3
AM-10	MOD	2	5,636	5	0.4	564	3.4
AM-11	LOW	1	1,032	4	0.1	21	0.1
AM-12	MOD	2	1,596	4	0.4	128	0.8
AM-13	MOD	2	4,830	4	0.4	386	2.3
AM-14	LOW	1	5,600	3	0.1	84	0.5
AM-15	LOW	1	6,033	3	0.1	90	0.5
AM-16	LOW	1	2,650	3	0.1	40	0.2
AM-17	MOD	2	2,994	4	0.4	240	1.4
AM-18	LOW	1	2,795	3	0.1	42	0.3
AM-19	LOW	1	2,397	3	0.1	36	0.2
EB-1	HIGH	3	9,409	6	1	2,823	17.0
EB-2	HIGH	3	8,347	6	1	2,504	15.1
EB-3	LOW	1	1,568	3	0.1	24	0.1
EB-4	LOW	1	1,452	3	0.1	22	0.1
EB-5	LOW	1	13,746	3	0.1	206	1.2
EB-6	LOW	1	3,878	2	0.1	39	0.2
EB-7	LOW	1	2,891	2	0.1	29	0.2
TR-1	LOW	1	532	2	0.1	5	0.0
TR-2	HIGH	3	1,557	4	1	311	1.9
TR-3	LOW	1	1,666	2	0.1	17	0.1
TR-4	LOW	1	3,395	2	0.1	34	0.2
TR-5	MOD	2	1,088	3	0.4	65	0.4
TR-6	LOW	1	1,444	2	0.1	14	0.1
TR-7	LOW	1	3,418	2	0.1	34	0.2
TR-8	MOD	2	3,910	3	0.4	235	1.4
TR-9	LOW	1	2,998	2	0.1	30	0.2
TR-10	LOW	1	2,636	2	0.1	26	0.2
TR-11	LOW	1	3,078	2	0.1	31	0.2
TR-12	LOW	1	3,319	2	0.1	33	0.2
TR-13	LOW	1	4,901	2	0.1	49	0.3
TR-14	LOW	1	2,972	2	0.1	30	0.2

TR-15	LOW	1	679	2	0.1	7	0.0
TR-16	LOW	1	2,558	2	0.1	26	0.2
TR-17	LOW	1	407	2	0.1	4	0.0
TR-18	LOW	1	677	2	0.1	7	0.0
TR-19	LOW	1	1,004	2	0.1	10	0.1
TR-20	LOW	1	583	2	0.1	6	0.0
TR-21	MOD	2	531	3	0.4	32	0.2
TR-22	MOD	2	2,477	3	0.4	149	0.9
TR-23	LOW	1	1,941	2	0.1	19	0.1
TR-24	LOW	1	362	2	0.1	4	0.0
TR-25	LOW	1	623	2	0.1	6	0.0
TR-26	LOW	1	858	2	0.1	9	0.1
TR-27	LOW	1	2,203	2	0.1	22	0.1
TR-28	LOW	1	3,346	2	0.1	33	0.2
TR-29	LOW	1	356	2	0.1	4	0.0
TR-30	MOD	2	1,710	3	0.4	103	0.6
TR-31	LOW	1	2,118	2	0.1	21	0.1
TR-32	MOD	2	2,232	3	0.4	134	0.8
TR-33	MOD	2	877	3	0.4	53	0.3
TR-34	LOW	1	547	2	0.1	5	0.0
TR-35	LOW	1	3,604	2	0.1	36	0.2
TR-36	LOW	1	2,087	2	0.1	21	0.1
TR-37	MOD	2	874	3	0.4	52	0.3
TR-38	LOW	1	3,353	2	0.1	34	0.2
TR-39	LOW	1	715	2	0.1	7	0.0
TR-40	LOW	1	4,899	2	0.1	49	0.3
TR-41	LOW	1	673	2	0.1	7	0.0
TR-42	LOW	1	3,913	2	0.1	39	0.2

The total estimated streambank erosion rate for the 33.5 stream miles in the Amity Creek Watershed is greater than 16,000 tons per year. This estimate does not include hillslope erosion, which is a clear problem in the Seven Bridges region. The column in Table 6 labeled % shows the relative percentage of total erosion rate attributed to each reach. This analysis identifies the four highest-priority reaches that together contribute about two-thirds of the total watershed erosion as follows:

Reach AM-7 (1,892 linear feet): 11 %
Reach AM-9 (4,417 linear feet): 21 %
Reach EB-1 (9,409 linear feet): 17 %
Reach EB-2 (8,347 linear feet): 15 %

Other stream reaches that each contribute more than 1 % of annual streambank erosion include AM-2, AM-4, AM-5, AM-6, AM-10, AM-13, AM-17, EB-5, TR-2, and TR-8. All of these reaches should be considered for future study and potential restoration projects.

RECOMMENDATIONS

Streambank and hillslope erosion should be addressed using a systematic geomorphic approach for improving watershed stability while optimizing water quality and biological conditions. Each high-priority reach should be further studied as it evolves through stream succession to determine the most effective restoration approach that will establish a trajectory toward equilibrium and optimal stream health.

Restoration plans should integrate hydrology, geomorphology, connectivity, water quality, and biology as a framework for setting objectives and implementing specific efforts. Hydrology considerations include baseflow, bankfull, and flood discharges. Geomorphology considerations include channel and floodplain dimensions to transport watershed flows and sediment, meander patterns that are appropriate for valley conditions, and bedforms that optimize energy dissipation and habitats. Connectivity considerations include ground and surface water, floodplain functions, and aquatic organism passage issues. Water quality and biology considerations include erosion control, healthy riparian vegetation, stormwater management, appropriate in-stream wood, and watershed stability.

The Appendix includes planning-level conceptual designs for the four highest-priority stream reaches that should be considered in resource allocation discussions. These plans are based on geomorphic principles of equilibrium sediment transport, floodplain connection, healthy riparian vegetation, and bedform diversity to support healthy aquatic biota.

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Amity Creek Reach 7 (AM-7)

Channel Type:	C4
Potential Stream Type:	C4
Valley Type:	Confined Valley
Concern Level:	Very High
Potential Projects:	1
Access:	Good

Amity Creek Reach 7 was identified as a very high priority and level of concern. Very large terraces and hillslope failure have contributed large amounts of sediment to the system. Vertical instability and horizontal movement was observed and to be extreme in locations. Moving the river away for the valley walls is the best option, giving more floodplain to reduce stress on the bank and limit sediment input. A priority 1 stream realignment is recommended for this reach.

Total Restored Linear Ft:	986 ft
Cost of Restoration:	$271,000 - $320,000 ($275 - $350 per/ft)

Geomorphic Stability:	Poor
Vegetation Condition:	Fair
Habitat Condition:	Poor

Assessment Forms

Stream:	Amity Creek			Location: Reach 7				
Observers:	MJG, GJ, JZ	Date: 10/27/2015		Stream Type: C4		Valley Type: CV		
Channel Dimension	Mean Bankfull Depth (ft): 1.8	Bankfull Width (ft): ~40	Cross-Sectional Area (ft^2): ~60	Width/Depth Ratio: 25	Entrenchment Ratio: <4.5			
Channel Pattern	Mean: / Range:	λ/W_{bkf}: 3 / 7	L_m/W_{bkf}: 4 / 12	R_c/W_{bkf}: 1 / 3	MWR: 2.2 / 3.5	Sinuosity: 1.2		
Streamflow	Bankfull Mean Velocity ($\bar{u}_{bkf}$) (ft/sec):	Bankfull Discharge (Q_{bkf}):	Estimation Method:	Drainage Area (mi^2): 6.99				
River Profile & Bed Features	Check: ☑ Riffle/Pool ☐ Step/Pool ☐ Plane Bed ☐ Convergence/Divergence ☐ Dunes/Antidunes/Smooth Bed							
	Max Bankfull Depth (ft):	Riffle: 3	Pool: 6	Depth Ratio (max to mean):	Riffle: 2	Pool: 4	Pool-to-Pool Spacing: Ratio 3	Slope — Valley: 0.004; Water Surface: 0.006
Level III Stream Stability Indices	Riparian Vegetation	Current Composition/Density: Cottenwood and Willow	Potential Composition/Density: Cottenwood and Willow	Remarks: Condition, Vigor & Usage of Existing Reach: not much tree veg				
	Flow Regime: P2	Stream Size & Order: S4	Meander Patterns: M3,M4	Depositional Patterns: B2	Debris/Channel Blockages: D4			
	Degree of Incision (Bank-Height Ratio): 1.05	Degree of Incision Stability Rating: Stable (not incised)	Modified Pfankuch Stability Rating (Numeric & Adjective Rating): N/A					
	Width/depth Ratio (W/d): 30	Reference W/d Ratio (W/d_{ref}): 18	Width/Depth Ratio State (W/d) / (W/d_{ref}): 1.67	W/d Ratio State Stability Rating: Unstable				
	Meander Width Ratio (MWR): 3.5	Reference MWR_{ref}: 2.5	Degree of confinement (MWR / MWR_{ref}): 1.4	MWR / MWR_{ref} Stability Rating: Unconfined				
Bank Erosion Summary	Length of Reach Studied (ft): 2000	Annual Streambank Erosion Rate: 1100 (tons/yr) 1.833333 (tons/yr/ft)	Curve Used: COLORADO	Remarks: High bank erosion				
Sediment Capacity (POWERSED)	☑ Sufficient Capacity ☑ Insufficient Capacity ☐ Excess Capacity	Remarks:						
Entrainment/ Competence	Largest Particle from Bar Sample (mm): 4	$\tau =$	$\tau^* =$	Existing Depth:	Required Depth:	Existing Slope:	Required Slope:	
Successional Stage Shift	E → C → HighW/D C → → →	Existing Stream State (Type): C	Potential Stream State (Type): C					
Lateral Stability	☐ *Stable* ☑ *Mod. Unstable* ☐ *Unstable* ☐ *Highly Unstable*	Remarks/causes: Meader Patern and W/d State						
Vertical Stability (Aggradation)	☐ *No Deposition* ☑ *Mod. Deposition* ☐ *Ex. Deposition* ☐ *Aggradation*	Remarks/causes: have slope and depth to move particles						
Vertical Stability (Degradation)	☑ *Not Incised* ☐ *Slightly Incised* ☐ *Mod. Incised* ☑ *Degradation*	Remarks/causes: Channel will downcut when bever dam goes						
Channel Enlargement	☑ *No Increase* ☐ *Slight Increase* ☑ *Mod. Increase* ☐ *Extensive*	Remarks/causes: Excpet to get wider over time						
Sediment Supply (Channel Source)	☑ *Low* ☐ *Moderate* ☐ *High* ☑ *Very High*	Remarks/causes: Large amounts due to banks						

RAPID GEOMORPHIC ASSESSMENT					
Watercourse	Amity Creek Reach 7		**Date:**	10/27/2016	
Location	Duluth, MN		**Reach:**	Reach 7	
Process (1)	GEOMORPHIC INDICATOR		PRESENT		FACTOR
	NO (2)	DESCRIPTION (3)	NO (4)	YES (5)	VALUE (6)
Evidence of Aggradation (AI)	1	Lobrate bar	x		
	2	Coarse Material in Riffle embedded		x	
	3	siltation in pools		x	
	4	medial bars	x		
	5	accreation on point bars		x	
	6	poor longitudinal sorting of bed materials		x	
	7	deposition in overbank zone	x		
		SUM OF INDICES	**3**	**4**	**0.57**
Evidence of Degradation (DI)	1	Exposed bridge footing		x	
	2	Exposed sanitary/storm sewer/pipeline ect..	x		
	3	Elevated Stormwater outfall(s)		x	
	4	undermined gabion baskets/concrete aprons/ect..	x		
	5	Scourpools d/s of culverts/stormwater outlets	x		
	6	Cur face on barm forms		x	
	7	Headcutting due to knick point migration		x	
	8	Terrace cut though older bar material		x	
	9	Suspended armour layer visible in bank		x	
	10	Channel worn into undisturbed overburden/bedrock		x	
		SUM OF INDICES	**3**	**7**	**0.70**
Evidence of Degradation (DI)	1	Fallen/leaning trees/fences posts ect.		x	
	2	Occurrence of Large Organic Debris		x	
	3	Exposed tree roots		x	
	4	basal scour inside meander bends		x	
	5	basal scour on both sides fo channel through riffle		x	
	6	gabion baskets/concrete walls/armor stone out flanked	x		
	7	Length of basal scour >50% though subject reach	x		
	8	Exposed length of previously burried piple cable/ect.	x		
	9	Fractur lines along top of bank		x	
	10	Exposed building foundation	x		
		SUM OF INDICES	**4**	**6**	**0.60**
Evidence of Aggradation (AI)	1	Formation of cute(s)	x		
	2	Evolution of single tread into multipile channel	x		
	3	Evolution of pool-riffle form to low bed felif form		x	
	4	Cutoff channel(s)		x	
	5	Formation of island(s)	x		
	6	Thalweg alignment out of phase with geometry		x	
	7	Bar forms poorly formed/reworked/removed		x	
		SUM OF INDICES	**3**	**4**	**0.57**
STABILITY INDEX (SI) = (AI +DI + WI + PI) / M					**0.61**

Stream Condition and Function: Score from 0 to 2 indicating natural stream integrity and health:
2 = Good; 1 = Fair; 0 = Poor

1. Upstream watershed impacts from stormwater, wastewater, or sediment ___0__

Good: no impacts from upstream sources	Fair: some minor impacts from upstream sources	Poor: major impacts from upstream sources

2. Local stream reach impacts from ditches, pipes, livestock, utilities, or roads ___0__

Good: no impacts from local sources	Fair: some minor impacts from local sources	Poor: major impacts from local sources

3. Channel dimension related to bankfull cross-section measurements ___1__

Good: natural equilibrium width, depth, and area dimensions expected for the watershed	Fair: some disequilibrium indicated by unnatural dimensions	Poor: major disequilibrium indicated by incision, widening, high variability, or channelized system

4. Channel pattern related to planform measurements __0___

Good: natural equilibrium meander pattern with sinuosity expected for the watershed	Fair: some disequilibrium indicated by unnatural pattern features	Poor: major disequilibrium indicated by tight bends, cutoffs, rapid down-valley meander migration, or straightening

5. Channel bed profile related to longitudinal profile measurements __0___

Good: natural equilibrium riffles, pools, steps, glides, and runs with bedform expected for the watershed	Fair: some disequilibrium indicated by unnatural or missing bedform features	Poor: major disequilibrium indicated by head cutting, plane bed, aggradation, or riffle migration into pools

6. Streambank stability and protection from erosion __0___

Good: low erodibility resulting from covered soil, low banks, deep roots, low stress	Fair: moderate erodibility resulting from some bare soil or erodible bank conditions	Poor: high erodibility resulting from bare soil, eroding bends, steep banks, high banks, lack of roots, high stress

7. Floodplain connection for bankfull flood access ___1__

Good: regular floodplain access with BHR < 1.2	Fair: some incision with BHR = 1.2–1.9	Poor: severely incised channel with BHR > 2

8. Floodplain morphology to dissipate flood energy and minimize erosion __1___

Good: low entrenchment with ER > 5 and no contractions	Fair: moderate entrenchment with ER = 1.5–5 and/or minor contractions	Poor: severe entrenchment with ER < 1.5 and/or major contractions

9. Riparian vegetation to provide shade, nutrient uptake, and food sources __2__

Good: healthy native plants growing in more than 90% of 50-ft buffer on both sides	Fair: healthy native plants growing in half to 90% of 50-ft buffer on both sides	Poor: healthy native plants growing in less than half of 50-ft buffer on both sides

10. Habitats including diverse bedform, large woody debris, leaf packs, root hairs __1___

Good: healthy aquatic micro- and macro-habitat features expected for watershed	Fair: lacking up to half of expected aquatic habitat features	Poor: lacking more than half of expected aquatic habitat features

11. Water quality and stream bed sediments __1___

Good: clear water with natural sediments expected for watershed	Fair: some turbidity and/or embeddedness affecting habitat conditions	Poor: excessive turbidity and/or embeddedness strongly affecting habitat conditions

12. Presence of desirable fish and macroinvertebrates expected for watershed __1___

Good: healthy communities including intolerant taxa	Fair: missing some intolerant taxa	Poor: lacking expected communities and/or dominated by tolerant taxa

Notes: _Poor Geomorphic Conditions with some Fair components. Major re-alignment is needed to fix most of this reach. Bank erosion is high.

Project Site 1 –Re-Alignment, Priority 1 Restoration

Location:
Latitude: 46°51'20.87"N
Longitude: 92° 1'32.36"W

Length:
Existing: 984 ft
Proposed: 1036 ft

Existing Conditions:
- Bank erosion
- High NBS
- Poor Bed Form
- Good vegetation buffer

Restoration Objectives:
- Provide stability
- Reduce risk on road
- Reduce Bank Erosion

Restoration Options:
- Priority 1 Restoration
- Channel Re-Alignment
- Tie into floodplain on right
- Use to wood, large boulders

Cost Estimate:
- ~$271,000 – $320,000

Reference Reach Data

Reach	Basin Creek	EF Arkansas River	Mitchell River Headwaters
Drainage Area	6.8	49.9	6.2
Valley Type	VII	V	VII
Stream Type	C4b	C4	B4
Wbkf (ft)	30.7	38.6	36.9
Abkf (ft^2)	57.4	66.7	75.5
WDR	18	22	18
D50	33	90	32
ER	2.8	2.9	1.95
Bank Erosion (ton/yr/ft)	0.0065	0.0045	0.0055
Slope (ft/ft)	0.023	0.018	0.025
Pool-Pool Spacing Ratio	6-8	5-6	1.5-3
MWR Ratio	9-12	10-12	4-6
BELT Ratio	3-6	4-7	2-4
ROC Ratio	2-4	2-5	2-4

Conceptual Design Data

Approximate Drainage Area (sq miles)	~10-14	~10-14	~10-14
Valley Type	Amity Creek	Amity Creek	Amity Creek
	UCV	**PCV**	**PCV**
Stream Type	C4 (Alluvial)	C4b (Alluvial)	B4 (Threshold)
Wbkf (ft)	38	25	28
Abkf (ft2)	60	60	60
Dbkf(ft)	1.5	1.39	1.27
WDR	24	18	22
D50 (mm)	90-100	120-140	180-200
Entrenchment Ratio	2.25	2.75	1.75
Bank Erosion (ton/yr/ft)	0.0055	0.0065	0.0025
Slope (ft/ft)	1%-2%	2%-3%	2%-4%
Pool-Pool Spacing Ratio	5.0-7.0	3.0 - 4.0	1.75-2.0
MWR Ratio (MWR * n/a for stream type)	4.0-7.0*	3.0-5.0*	1.25-1.75*
MLR Ratio (MLR * n/a for stream type)	8.0-10.0*	4.50-5.50	2.5-3.0*
Rc Ratio	3.0-4.5	2.5-4.0	3.5-5.0
K, Sinuosity	1.2	1.05	1.02
Applied Shear Stress (lbs/sqft)	1.6	2.6	4.0
Manning's "n"	0.045	0.045	0.065
Estimated Velocity (ft/s)	5.5	7.1	6.0
Unit Stream Power (ft-lbs/s-ft)	8.7	18.6	23.9

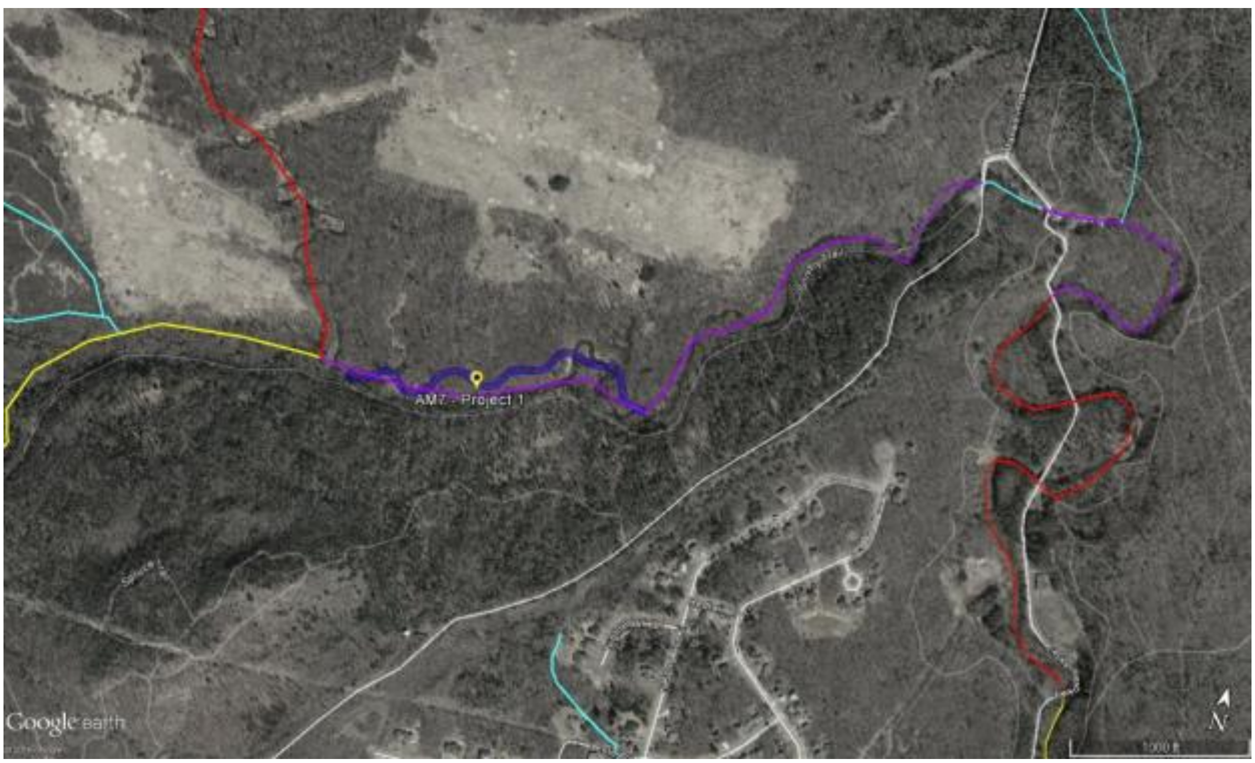
Amity Creek Reach 9 (AM-9)

Channel Type:	C4
Potential Stream Type:	C4
Valley Type:	Confined Valley
Concern Level:	Very High
Potential Projects:	1
Access:	Good

Amity Creek Reach 9 was identified as a very high priority and level of concern. Vertical instability and horizontal movement was observed and to be extreme in locations. A beaver dam was also present causing sediment transport problems and instability in the reach. There is a natural walkway that is in danger on this project that is of concern. A priority 1 stream realignment is recommended for this reach.

Total Restored Liner Foot:	2100 ft
Cost of Restoration:	\$525,000 - \$630,000 (\$250 - \$300 per/ft)

Geomorphic Stability:	Poor
Vegetation Condition:	Fair
Habitat Condition:	Fair



Assessment Forms

Stream:	Amity Creek				Location: Reach 7				
Observers:	MJG, GJ, JZ		Date: 10/27/2015		Stream Type: C4		Valley Type: CV		
Channel Dimension	Mean Bankfull Depth (ft): 1.8		Bankfull Width (ft): ~40		Cross-Sectional Area (ft^2): ~60		Width/Depth Ratio: 25		Entrenchment Ratio: <4.5
Channel Pattern	Mean: / Range:	λ/W_{bkf}: 3 / 7		L_m/W_{bkf}: 4 / 12		R_c/W_{bkf}: 1 / 3	MWR: 2.2 / 3.5		Sinuosity: 1.2
Streamflow	Bankfull Mean Velocity ($\bar{u}_{bkf}$) (ft/sec):		Bankfull Discharge (Q_{bkf}):		Estimation Method:				Drainage Area (mi^2): 6.99
River Profile & Bed Features	Check: [x] Riffle/Pool	[ ] Step/Pool	[ ] Plane Bed	[ ] Convergence/Divergence	[ ] Dunes/Antidunes/Smooth Bed				
	Max Bankfull Depth (ft):	Riffle: 3	Pool: 6	Depth Ratio (max to mean): Riffle: 2	Pool: 4	Pool-to-Pool Spacing:	Ratio: 3	Slope: Valley: 0.004	Water Surface: 0.006
Level III Stream Stability Indices	Riparian Vegetation	Current Composition/Density: Cottenwood and Willow		Potential Composition/Density: Cottenwood and Willow		Remarks: Condition, Vigor & Usage of Existing Reach: not much tree veg			
	Flow Regime: P2	Stream Size & Order: S4		Meander Patterns: M3,M4		Depositional Patterns: B2		Debris/Channel Blockages: D4	
	Degree of Incision (Bank-Height Ratio): 1.05		Degree of Incision Stability Rating: Stable (not incised)			Modified Pfankuch Stability Rating (Numeric & Adjective Rating): N/A			
	Width/depth Ratio (W/d): 30		Reference W/d Ratio (W/d_{ref}): 18		Width/Depth Ratio State (W/d) / (W/d_{ref}): 1.67			W/d Ratio State Stability Rating: Unstable	
	Meander Width Ratio (MWR): 3.5		Reference MWR_{ref}: 2.5		Degree of confinement (MWR / MWR_{ref}): 1.4			MWR / MWR_{ref} Stability Rating: Unconfined	
Bank Erosion Summary	Length of Reach Studied (ft): 2000		Annual Streambank Erosion Rate: 1100 (tons/yr)	1.833333 (tons/yr/ft)	Curve Used: COLORADO		Remarks: High bank erosion		
Sediment Capacity (POWERSED)	[x] Sufficient Capacity	[x] Insufficient Capacity	[ ] Excess Capacity			Remarks:			
Entrainment/ Competence	Largest Particle from Bar Sample (mm): 4		$\tau =$	$\tau^*=$	Existing Depth:	Required Depth:	Existing Slope:	Required Slope:	
Successional Stage Shift	E → C → HighW/D C → → →					Existing Stream State (Type): C		Potential Stream State (Type): C	
Lateral Stability	[ ] Stable	[x] Mod. Unstable	[ ] Unstable	[ ] Highly Unstable		Remarks/causes: Meader Patern and W/d State			
Vertical Stability (Aggradation)	[ ] No Deposition	[x] Mod. Deposition	[ ] Ex. Deposition	[ ] Aggradation		Remarks/causes: have slope and depth to move particles			
Vertical Stability (Degradation)	[x] Not Incised	[ ] Slightly Incised	[ ] Mod. Incised	[x] Degradation		Remarks/causes: Channel will downcut when bever dam goes			
Channel Enlargement	[x] No Increase	[ ] Slight Increase	[x] Mod. Increase	[ ] Extensive		Remarks/causes: Excpet to get wider over time			
Sediment Supply (Channel Source)	[x] Low	[ ] Moderate	[ ] High	[x] Very High		Remarks/causes: Large amounts due to banks			

RAPID GEOMORPHIC ASSESSMENT					
Watercourse	Amity Creek Reach 7	Date:	10/27/2016		
Location	Duluth, MN	Reach:	Reach 7		
Process (1)	GEOMORPHIC INDICATOR		PRESENT		FACTOR
	NO (2)	DESCRIPTION (3)	NO (4)	YES (5)	VALUE (6)
Evidence of Aggradation (AI)	1	Lobrate bar	x		
	2	Coarse Material in Riffle embedded		x	
	3	siltation in pools		x	
	4	medial bars	x		
	5	accreation on point bars		x	
	6	poor longitudinal sorting of bed materials		x	
	7	deposition in overbank zone	x		
		SUM OF INDICES	**3**	**4**	**0.57**
Evidence of Degradation (DI)	1	Exposed bridge footing		x	
	2	Exposed sanitary/storm sewer/pipeline ect..	x		
	3	Elevated Stormwater outfall(s)		x	
	4	undermined gabion baskets/concrete aprons/ect..	x		
	5	Scourpools d/s of culverts/stormwater outlets	x		
	6	Cur face on barm forms		x	
	7	Headcutting due to knick point migration		x	
	8	Terrace cut though older bar material		x	
	9	Suspended armour layer visible in bank		x	
	10	Channel worn into undisturbed overburden/bedrock		x	
		SUM OF INDICES	**3**	**7**	**0.70**
Evidence of Degradation (DI)	1	Fallen/leaning trees/fences posts ect.		x	
	2	Occurrence of Large Organic Debris		x	
	3	Exposed tree roots		x	
	4	basal scour inside meander bends		x	
	5	basal scour on both sides fo channel through riffle		x	
	6	gabion baskets/concrete walls/armor stone out flanked	x		
	7	Length of basal scour >50% though subject reach	x		
	8	Exposed length of previously burried piple cable/ect.	x		
	9	Fractur lines along top of bank		x	
	10	Exposed building foundation	x		
		SUM OF INDICES	**4**	**6**	**0.60**
Evidence of Aggradation (AI)	1	Formation of cute(s)	x		
	2	Evolution of single tread into multipile channel	x		
	3	Evolution of pool-riffle form to low bed felif form		x	
	4	Cutoff channel(s)		x	
	5	Formation of island(s)	x		
	6	Thalweg alignment out of phase with geometry		x	
	7	Bar forms poorly formed/reworked/removed		x	
		SUM OF INDICES	**3**	**4**	**0.57**
STABILITY INDEX (SI) = (AI +DI + WI + PI) / M					**0.61**

Stream Condition and Function: Score from 0 to 2 indicating natural stream integrity and health:
2 = Good;   1 = Fair;   0 = Poor

1. Upstream watershed impacts from stormwater, wastewater, or sediment **___0__**

Good: no impacts from upstream sources	Fair: some minor impacts from upstream sources	Poor: major impacts from upstream sources

2. Local stream reach impacts from ditches, pipes, livestock, utilities, or roads **___0__**

Good: no impacts from local sources	Fair: some minor impacts from local sources	Poor: major impacts from local sources

3. Channel dimension related to bankfull cross-section measurements **___1__**

Good: natural equilibrium width, depth, and area dimensions expected for the watershed	Fair: some disequilibrium indicated by unnatural dimensions	Poor: major disequilibrium indicated by incision, widening, high variability, or channelized system

4. Channel pattern related to planform measurements **__0___**

Good: natural equilibrium meander pattern with sinuosity expected for the watershed	Fair: some disequilibrium indicated by unnatural pattern features	Poor: major disequilibrium indicated by tight bends, cutoffs, rapid down-valley meander migration, or straightening

5. Channel bed profile related to longitudinal profile measurements **__0___**

Good: natural equilibrium riffles, pools, steps, glides, and runs with bedform expected for the watershed	Fair: some disequilibrium indicated by unnatural or missing bedform features	Poor: major disequilibrium indicated by head cutting, plane bed, aggradation, or riffle migration into pools

6. Streambank stability and protection from erosion **__0___**

Good: low erodibility resulting from covered soil, low banks, deep roots, low stress	Fair: moderate erodibility resulting from some bare soil or erodible bank conditions	Poor: high erodibility resulting from bare soil, eroding bends, steep banks, high banks, lack of roots, high stress

7. Floodplain connection for bankfull flood access ___1__

Good: regular floodplain access with BHR < 1.2	Fair: some incision with BHR = 1.2–1.9	Poor: severely incised channel with BHR > 2

8. Floodplain morphology to dissipate flood energy and minimize erosion __1___

Good: low entrenchment with ER > 5 and no contractions	Fair: moderate entrenchment with ER = 1.5–5 and/or minor contractions	Poor: severe entrenchment with ER < 1.5 and/or major contractions

9. Riparian vegetation to provide shade, nutrient uptake, and food sources __2__

Good: healthy native plants growing in more than 90% of 50-ft buffer on both sides	Fair: healthy native plants growing in half to 90% of 50-ft buffer on both sides	Poor: healthy native plants growing in less than half of 50-ft buffer on both sides

10. Habitats including diverse bedform, large woody debris, leaf packs, root hairs __1___

Good: healthy aquatic micro- and macro-habitat features expected for watershed	Fair: lacking up to half of expected aquatic habitat features	Poor: lacking more than half of expected aquatic habitat features

11. Water quality and stream bed sediments __1___

Good: clear water with natural sediments expected for watershed	Fair: some turbidity and/or embeddedness affecting habitat conditions	Poor: excessive turbidity and/or embeddededness strongly affecting habitat conditions

12. Presence of desirable fish and macroinvertebrates expected for watershed __1___

Good: healthy communities including intolerant taxa	Fair: missing some intolerant taxa	Poor: lacking expected communities and/or dominated by tolerant taxa

Notes: _Poor Geomorphic Conditions with some Fair components. Major re-alignment is needed to fix most of this reach. Bank erosion is high.

Project Site 1 –Re-Alignment, Priority 1 Restoration

Location:
Latitude: 46°51'20.87"N
Longitude: 92° 1'32.36"W

Existing Conditions:

- Bank erosion
- High NBS
- Poor Bed Form
- Good vegetation buffer

Restoration Objectives:

- Provide stability
- Reduce risk on road
- Reduce Bank Erosion

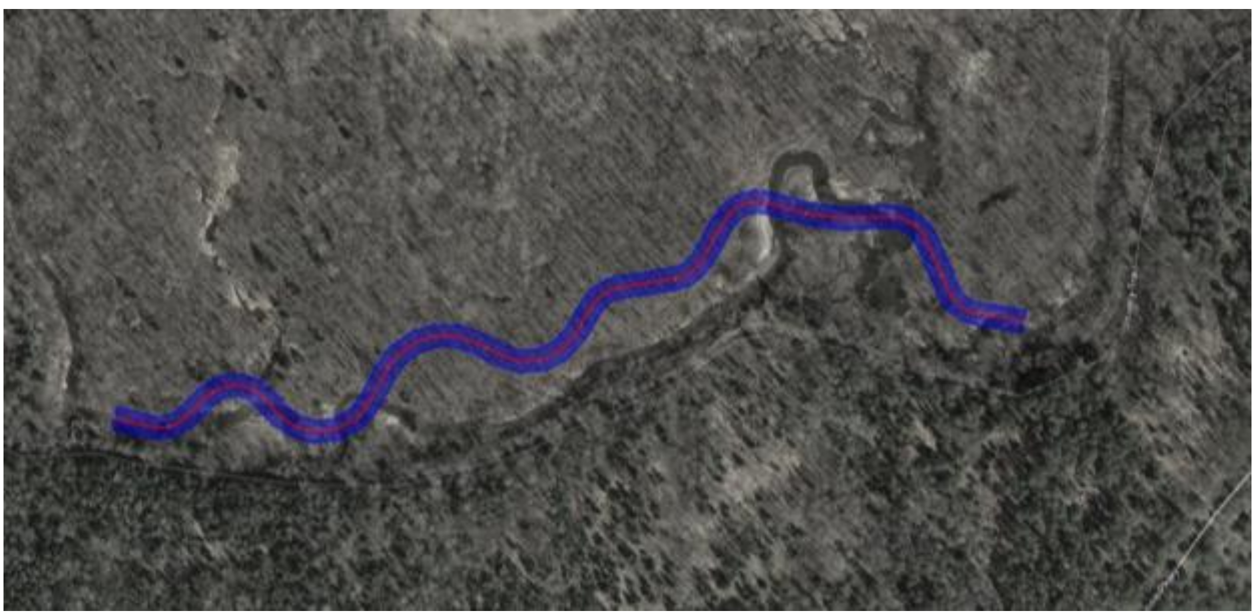
Length:
Existing: 2400 ft
Proposed: 2100 ft

Restoration Options:

- Priority 1 Restoration
- Channel Re-Alignment
- Tie into floodplain on left

Cost Estimate:

- ~$525,000 – $630,000



Reference Reaches

Reach	Basin Creek	EF Arkansas River	Mitchell River Headwaters
Drainage Area	6.8	49.9	6.2
Valley Type	VII	V	VII
Stream Type	C4b	C4	B4
Wbkf (ft)	30.7	38.6	36.9
Abkf (ft^2)	57.4	66.7	75.5
WDR	18	22	18
D50	33	90	32
ER	2.8	2.9	1.95
Bank Erosion (ton/yr/ft)	0.0065	0.0045	0.0055
Slope (ft/ft)	0.023	0.018	0.025
Pool-Pool Spacing Ratio	6-8	5-6	1.5-3
MWR Ratio	9-12	10-12	4-6
BELT Ratio	3-6	4-7	2-4
ROC Ratio	2-4	2-5	2-4

Conceptual Design Data

Approximate Drainage Area (sqmiles)	~10-14	~10-14	~10-14
Valley Type	Amity Creek	Amity Crek	Amity Creek
	UCV	**PCV**	**PCV**
Stream Type	C4 (Alluvial)	C4b (Alluvial)	B4 (Threshold)
Wbkf (ft)	38	25	28
Abkf (ft2)	60	60	60
Dbkf(ft)	1.5	1.39	1.27
WDR	24	18	22
D50 (mm)	90-100	120-140	180-200
Entrenchment Ratio	2.25	2.75	1.75
Bank Erosion (ton/yr/ft)	0.0055	0.0065	0.0025
Slope (ft/ft)	1%-2%	2%-3%	2%-4%
Pool-Pool Spacing Ratio	5.0-7.0	3.0 - 4.0	1.75-2.0
MWR Ratio (MWR * n/a for stream type)	4.0-7.0*	3.0-5.0*	1.25-1.75*
MLR Ratio (MLR * n/a for stream type)	8.0-10.0*	4.50-5.50	2.5-3.0*
Rc Ratio	3.0-4.5	2.5-4.0	3.5-5.0
K, Sinuosity	1.2	1.05	1.02
Applied Shear Stress (lbs/sqft)	1.6	2.6	4.0
Manning's "n"	0.045	0.045	0.065
Estimated Velocity (ft/s)	5.5	7.1	6.0
Unit Stream Power (ft-lbs/s-ft)	8.7	18.6	23.9

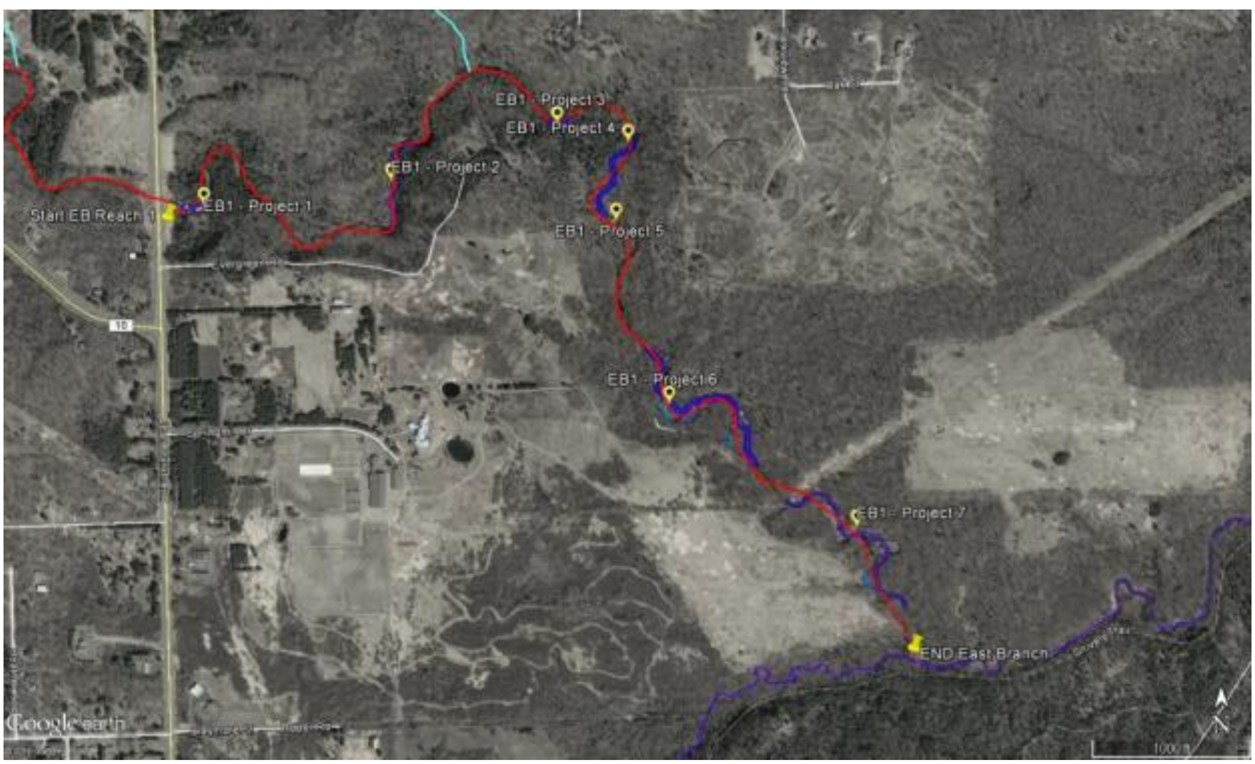
East Branch 1 (EB-1)

Channel Type:	C4
Potential Stream Type:	C4
Valley Type:	Partially Unconfined Valley
Concern Level:	High
Potential Projects:	7
Access:	Moderate/Good

East Branch Reach 1 was identified as a high priority and level of concern. Horizontal instability and migration was observed and documented through the reach. High levels of bank erosion and departure from stable conditions were observed. Poor habitat and vegetation in spots were noted. All sites are located on public land. 7 potential projects were identified that range from bank stabilization to major realignment. Post restoration would see results in 95% sediment reduction. There is no infrastructure in danger within the reach.

Total Restored Liner Foot:	5080 ft
Cost of Restoration:	$1,115,000 - $1,300,000 ($219 - $273 per/ft)

Geomorphic Stability:	Poor
Vegetation Condition:	Fair
Habitat Condition:	Fair



Assessment Forms for East Branch Reach 1 Projects

Stream:	East Branch					Location:	Reach 1				
Observers:	MJG, GJ, JZ		Date:	10/27/2015		Stream Type:	C4		Valley Type:	PUCV	
Channel Dimension	Mean Bankfull Depth (ft):	1.5	Bankfull Width (ft):	~42	Cross-Sectional Area (ft^2):	~55	Width/Depth Ratio:	33	Entrenchment Ratio:	<4.5	
Channel Pattern	Mean: Range:	λ/W_{bkf}:	5 7	L_m/W_{bkf}:	6 8	R_c/W_{bkf}:	2 3	MWR:	2.2 3.5	Sinuosity:	1.2
Streamflow	Bankfull Mean Velocity ($\bar{u}_{bkf}$) (ft/sec):	~4	Bankfull Discharge (Q_{bkf}):	160	Estimation Method:	Mannings	Drainage Area (mi^2):	7.55			
River Profile & Bed Features	Check: ☑ Riffle/Pool ☐ Step/Pool ☐ Plane Bed ☐ Convergence/Divergence ☐ Dunes/Antidunes/Smooth Bed										
	Max Bankfull Depth (ft):	Riffle: 3	Pool: 6	Depth Ratio (max to mean):	Riffle: 2	Pool: 4	Pool-to-Pool Spacing:	Ratio: 1.283	Slope: Valley: 0.004	Water Surface:	0.006
Level III Stream Stability Indices	Riparian Vegetation	Current Composition/Density: Cottonwood and Willow		Potential Composition/Density: Cottonwood and Willow			Remarks: Condition, Vigor & Usage of Existing Reach: not much tree veg				
	Flow Regime:	P2	Stream Size & Order:	S4	Meander Patterns:	M2,M3	Depositional Patterns:	B2,B4	Debris/Channel Blockages:	D2	
	Degree of Incision (Bank-Height Ratio):		Degree of Incision Stability Rating:	Stable (not incised)	Modified Pfankuch Stability Rating (Numeric & Adjective Rating):	N/A					
	Width/depth Ratio (W/d):	1.8	Reference W/d Ratio (W/d_{ref}):	22	Width/Depth Ratio State (W/d) / (W/d_{ref}):	1.60	W/d Ratio State Stability Rating:	Highly Unstable			
	Meander Width Ratio (MWR):	3.5	Reference MWR_{ref}:	3.8	Degree of confinement (MWR / MWR_{ref}):	0.92105263	MWR / MWR_{ref} Stability Rating:	Moderate Departure			
Bank Erosion Summary	Length of Reach Studied (ft):	1400	Annual Streambank Erosion Rate: 112 (tons/yr)	0.186667 (tons/yr/ft)	Curve Used: COLORADO	Remarks: High Bank Erosion					
Sediment Capacity (POWERSED)	☐ Sufficient Capacity	☑ Insufficient Capacity	☐ Excess Capacity	Remarks: Need Better W/D to Move							
Successional Stage Shift	E → C → HighW/D C → F → →				Existing Stream State (Type):	C	Potential Stream State (Type):	C			
Lateral Stability	☐ Stable	☐ Mod. Unstable	☐ Unstable	☑ Highly Unstable	Remarks/causes: High Bank Eroison W/D State						
Vertical Stability (Aggradation)	☐ No Deposition	☑ Mod. Deposition	☐ Ex. Deposition	☐ Aggradation	Remarks/causes: have slope and depth to move particles						
Vertical Stability (Degradation)	☐ Not Incised	☐ Slightly Incised	☐ Mod. Incised	☑ Degradation	Remarks/causes: High Incision						
Channel Enlargement	☐ No Increase	☐ Slight Increase	☑ Mod. Increase	☐ Extensive	Remarks/causes: Excpet to get wider over time						
Sediment Supply (Channel Source)	☐ Low	☐ Moderate	☐ High	☑ Very High	Remarks/causes: Excess Sediment, Bank Failure, Head Cutting						

		RAPID GEOMORPHIC ASSESSMENT			
Watercourse	East Branch		**Date:**	10/27/2016	
Location	Duluth, MN		**Reach:**	Reach 1	
Process (1)	GEOMORPHIC INDICATOR		PRESENT		FACTOR
	NO (2)	DESCRIPTION (3)	NO (4)	YES (5)	VALUE (6)
Evidence of Aggradation (AI)	1	Lobrate bar	x		
	2	Coarse Material in Riffle embedded		x	
	3	siltation in pools		x	
	4	medial bars		x	
	5	accreation on point bars			
	6	poor longitudinal sorting of bed materials		x	
	7	deposition in overbank zone		x	
		SUM OF INDICES	**1**	**5**	**0.83**
Evidence of Degradation (DI)	1	Exposed bridge footing	x		
	2	Exposed sanitary/storm sewer/pipeline ect..	x		
	3	Elevated Stormwater outfall(s)	x		
	4	undermined gabion baskets/concrete aprons/ect..	x	x	
	5	Scourpools d/s of culverts/stormwater outlets			
	6	Cur face on barm forms			
	7	Headcutting due to knick point migration		x	
	8	Terrace cut though older bar material		x	
	9	Suspended armour layer visible in bank		x	
	10	Channel worn into undisturbed overburden/bedrock		x	
		SUM OF INDICES	**4**	**5**	**0.56**
Evidence of Degradation (DI)	1	Fallen/leaning trees/fences posts ect.		x	
	2	Occurrence of Large Organic Debris		x	
	3	Exposed tree roots		x	
	4	basal scour inside meander bends		x	
	5	basal scour on both sides fo channel through riffle		x	
	6	gabion baskets/concrete walls/armor stone out flanked		x	
	7	Length of basal scour >50% though subject reach	x		
	8	Exposed length of previously burried piple cable/ect.	x		
	9	Fractur lines along top of bank	x		
	10	Exposed building foundation	x		
		SUM OF INDICES	**4**	**6**	**0.60**
Evidence of Aggradation (AI)	1	Formation of cute(s)	x		
	2	Evolution of single tread into multipile channel	x		
	3	Evolution of pool-riffle form to low bed felif form		x	
	4	Cutoff channel(s)	x		
	5	Formation of island(s)	x		
	6	Thalweg alignment out of phase with geometry		x	
	7	Bar forms poorly formed/reworked/removed		x	
		SUM OF INDICES	**4**	**3**	**0.43**
STABILITY INDEX (SI) = (AI +DI + WI + PI) / M					**0.60**

Stream Condition and Function: Score from 0 to 2 indicating natural stream integrity and health:
2 = Good; 1 = Fair; 0 = Poor

1. Upstream watershed impacts from stormwater, wastewater, or sediment ___1__

Good: no impacts from upstream sources	Fair: some minor impacts from upstream sources	Poor: major impacts from upstream sources

2. Local stream reach impacts from ditches, pipes, livestock, utilities, or roads ___2__

Good: no impacts from local sources	Fair: some minor impacts from local sources	Poor: major impacts from local sources

3. Channel dimension related to bankfull cross-section measurements ___1__

Good: natural equilibrium width, depth, and area dimensions expected for the watershed	Fair: some disequilibrium indicated by unnatural dimensions	Poor: major disequilibrium indicated by incision, widening, high variability, or channelized system

4. Channel pattern related to planform measurements __0___

Good: natural equilibrium meander pattern with sinuosity expected for the watershed	Fair: some disequilibrium indicated by unnatural pattern features	Poor: major disequilibrium indicated by tight bends, cutoffs, rapid down-valley meander migration, or straightening

5. Channel bed profile related to longitudinal profile measurements __1___

Good: natural equilibrium riffles, pools, steps, glides, and runs with bedform expected for the watershed	Fair: some disequilibrium indicated by unnatural or missing bedform features	Poor: major disequilibrium indicated by head cutting, plane bed, aggradation, or riffle migration into pools

6. Streambank stability and protection from erosion __0___

Good: low erodibility resulting from covered soil, low banks, deep roots, low stress	Fair: moderate erodibility resulting from some bare soil or erodible bank conditions	Poor: high erodibility resulting from bare soil, eroding bends, steep banks, high banks, lack of roots, high stress

7. Floodplain connection for bankfull flood access ___1__

Good: regular floodplain access with BHR < 1.2	Fair: some incision with BHR = 1.2–1.9	Poor: severely incised channel with BHR > 2

8. Floodplain morphology to dissipate flood energy and minimize erosion __1___

Good: low entrenchment with ER > 5 and no contractions	Fair: moderate entrenchment with ER = 1.5–5 and/or minor contractions	Poor: severe entrenchment with ER < 1.5 and/or major contractions

9. Riparian vegetation to provide shade, nutrient uptake, and food sources __1.5__

Good: healthy native plants growing in more than 90% of 50-ft buffer on both sides	Fair: healthy native plants growing in half to 90% of 50-ft buffer on both sides	Poor: healthy native plants growing in less than half of 50-ft buffer on both sides

10. Habitats including diverse bedform, large woody debris, leaf packs, root hairs __1___

Good: healthy aquatic micro- and macro-habitat features expected for watershed	Fair: lacking up to half of expected aquatic habitat features	Poor: lacking more than half of expected aquatic habitat features

11. Water quality and stream bed sediments __2___

Good: clear water with natural sediments expected for watershed	Fair: some turbidity and/or embeddedness affecting habitat conditions	Poor: excessive turbidity and/or embeddedness strongly affecting habitat conditions

12. Presence of desirable fish and macroinvertebrates expected for watershed __2___

Good: healthy communities including intolerant taxa	Fair: missing some intolerant taxa	Poor: lacking expected communities and/or dominated by tolerant taxa

Notes: _Poor Geomorphic Conditions with some Fair components. Major re-alignment is needed to fix most of this reach. Bank erosion is high.

Project Site 1 – Slight Re-Alignment/Bank Stabilization

Location:
Latitude: 46°51'49.47"N
Longitude: 92° 2'48.42"W

Length:
Existing: 250 ft
Proposed: 250 ft

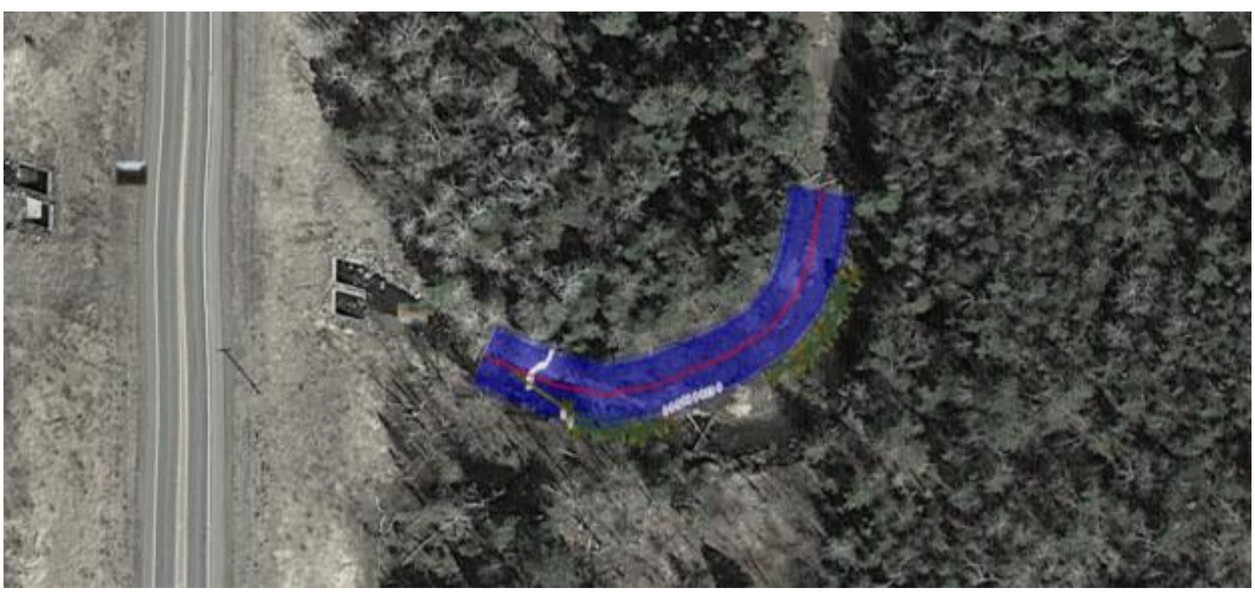
Existing Conditions:
- Bank erosion downstream of culvert
- High NBS
- Large Boulders present
- Good vegetation buffer

Restoration Options:
- Bank Stabilization/Toe Wood
- Slight Channel Re-Alignment
- Re-use boulders for toe protection

Restoration Objectives:
- Provide more floodplain to reduce stress
- Reduce Bank Erosion

Cost Estimate:
- ~$75,000-$125,000





Project Site 2 – Stream Re-Alignment, Priority 1 Restoration

Location:
Latitude: 46°51'50.72"N
Longitude: 92° 2'31.26"W

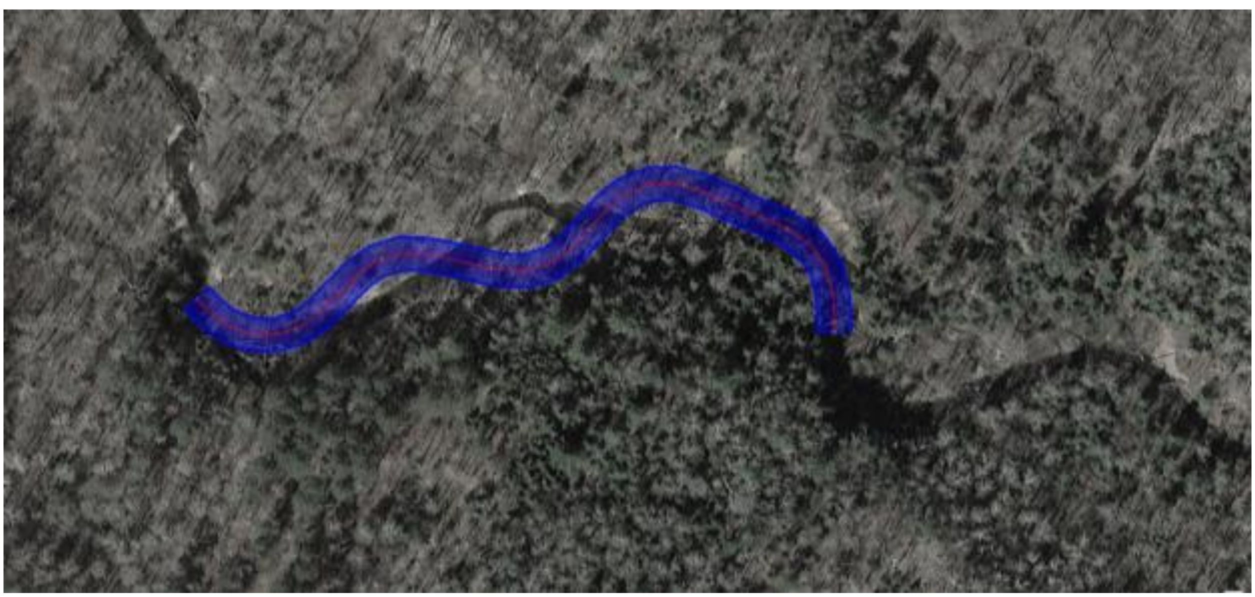
Existing Conditions:
- Aggradation of the bed causing mid-channel bars and last of sediment transport ability
- Mod BHR
- Poor Bed form

Restoration Objectives:
- Establish stable channel pattern and dimensions
- Reconnect to floodplain

Length:
Existing: 800 ft
Proposed: 734 ft

Restoration Options:
- Priority 1 Restoration
- Channel Re-Alignment
- Use of Toe Wood, Natural Constructed Riffles

Cost Estimate:
- ~$125,000-$175,000

Project Site 3 – Bank Stabilization

Location:
Latitude: 46°51'54.04"N
Longitude: 92° 2'15.96"W

Existing Conditions:
- Bank Erosion on river left
- High NBS

Restoration Objectives:
- Move away from bank, create bankfull floodplain bench to reduce stresses

Length:
Existing: 150 ft
Proposed: 150 ft

Restoration Options:
- Bank Stabilization
- Use of Toe Wood, log/rock vanes and creation of floodplain bench

Cost Estimate:
- ~$35,000-$50,000

Project Site 4 – Stream Re-Alignment, Priority 1 Restoration

Location:
Latitude: 46°51'52.82"N
Longitude: 92° 2'9.50"W

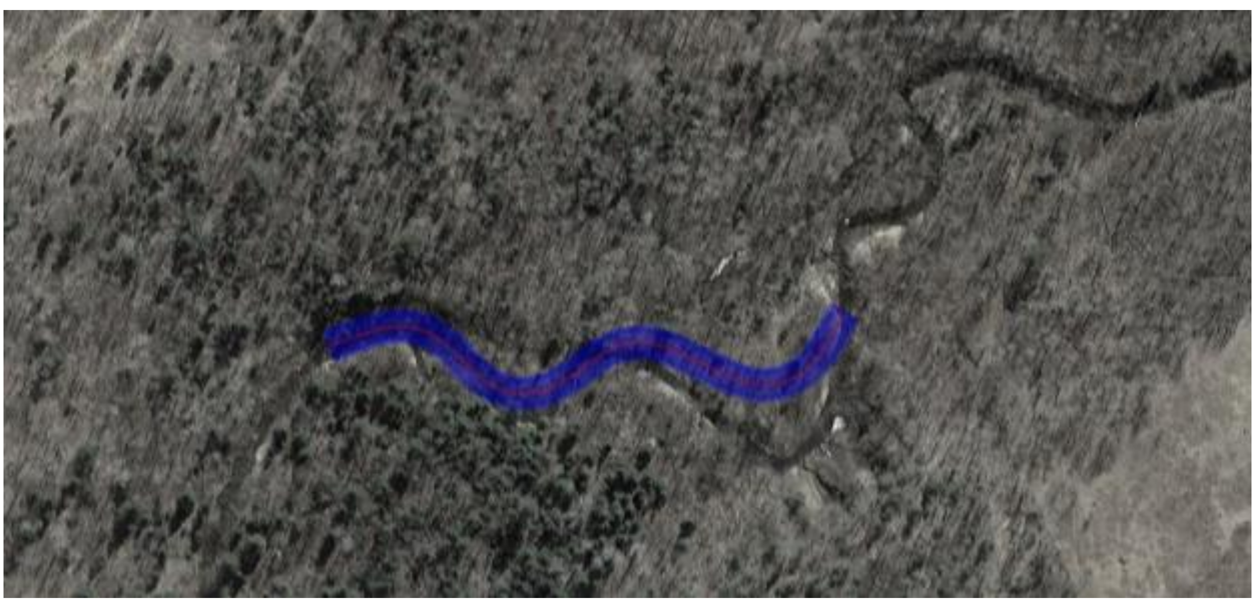
Length:
Existing: 715 ft
Proposed: 630 ft

Existing Conditions:
- Poor Pool-Pool Spacing
- High areas of bank erosion
- High terrace wall
- Very high NBS

Restoration Options:
- Priority 1 Restoration
- Channel Re-Alignment
- Re-connect floodplain
- Use of Toe Wood, Natural Constructed Riffles, boulder clusters

Restoration Objectives:
- Establish stable channel pattern and dimensions
- Move away from terrace walls

Cost Estimate:
- ~$175,000 – $200,000



Project Site 5 – Slight Re-Alignment/Bank Stabilization

Location:
Latitude: 46°51'47.93"N
Longitude: 92° 2'10.77"W

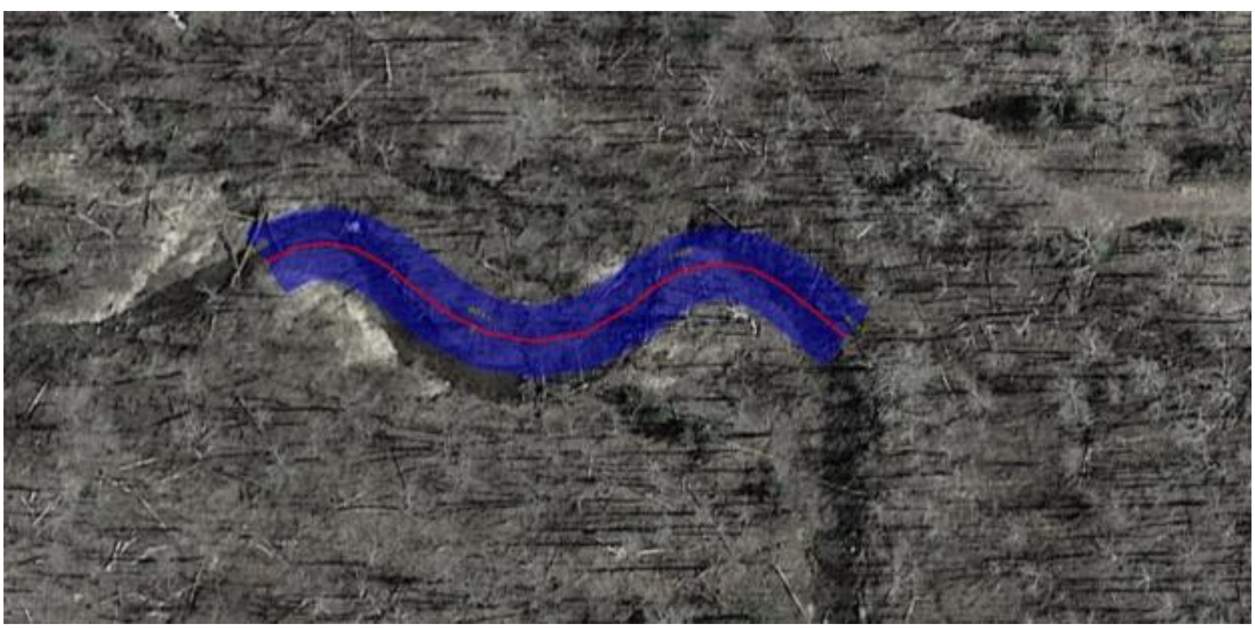
Length:
Existing: 1490 ft
Proposed: 1374 ft

Existing Conditions:
- Horizontal Bank Migration
- High NBS
- High Terrace Walls

Restoration Objectives:
- Reduce Bank Erosion
- Create Floodplain
- Move Sediment Bars

Restoration Options:
- Slight Re-Alignment
- Bank Stabilization
- Use of Toe Wood, Boulder Clusters, Log Vanes

Cost Estimate:
- ~$125,000 - $150,000



Project Site 6 – Stream Re-Alignment, Priority 1 Restoration

Location:
Latitude: 46°51'35.20"N
Longitude: 92° 1'59.67"W

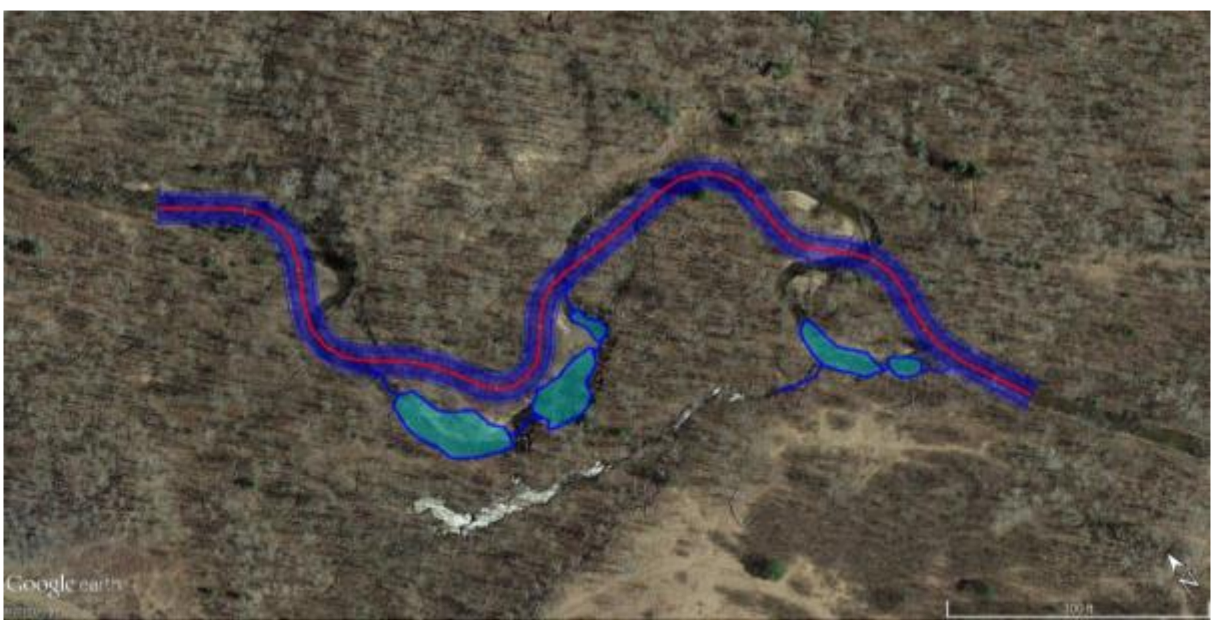
Length:
Existing: 1490 ft
Proposed: 1374 ft

Existing Conditions:
- Severe down valley migration patterns
- High areas of bank erosion
- Lack of Pool – Pool Spacing

Restoration Objectives:
- Establish stable channel pattern and dimensions
- Reduce Bank Erosion
- Provide Better Habitat

Restoration Options:
- Priority 1 Restoration
- Channel Re-Alignment
- Off-Channel Oxbows
- Use of Toe Wood, Natural Constructed Riffles

Cost Estimate:
- ~$295,000-$335,000



Project Site 7 – Stream Re-Alignment, Priority 2 Restoration

Location:
Latitude: 46°51'28.46"N
Longitude: 92° 1'49.40"W

Existing Conditions:
- Severe down valley migration patterns
- High areas of bank erosion
- Lack of Pool – Pool Spacing

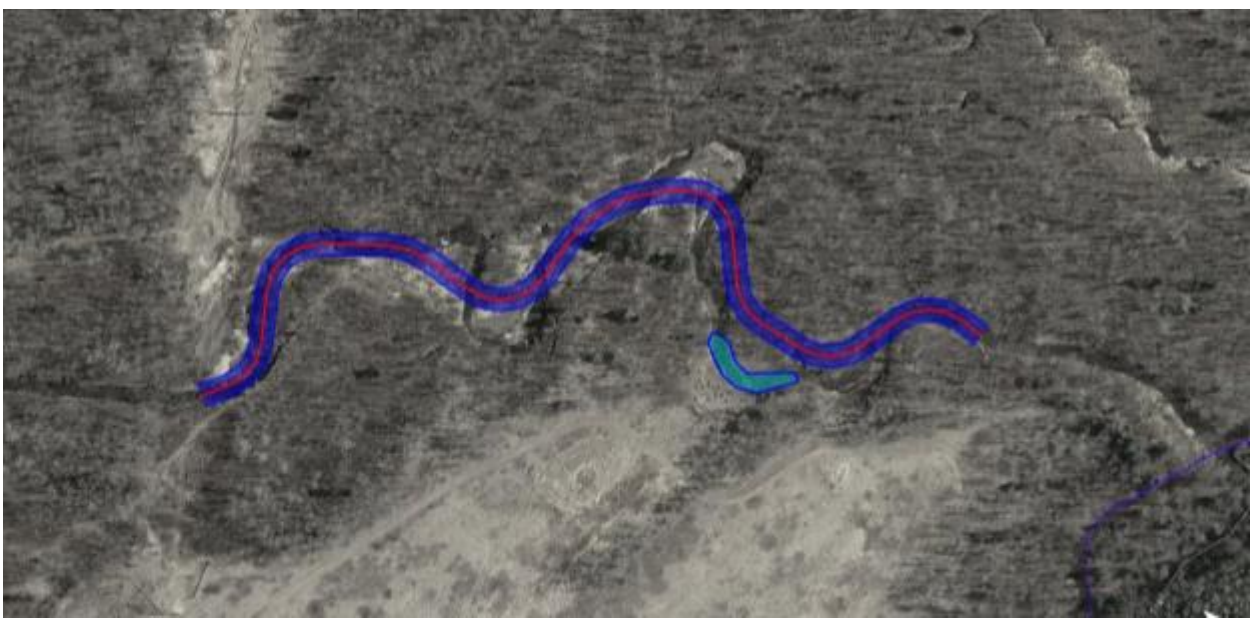
Restoration Objectives:
- Establish stable channel pattern and dimensions
- Reduce Bank Erosion
- Provide Better Habitat

Length:
Existing: 1450 ft
Proposed: 1390 ft

Restoration Options:
- Priority 2 Restoration
- Channel Re-Alignment
- Off-Channel Oxbows
- Use of Toe Wood, Natural Constructed Riffles, Boulder Clusters

Cost Estimate:
- ~$285,000-$330,000





Conceptual Design Data for East Branch Reach 1 Projects

Table - East Branch Reference Reaches

Reach	Basin Creek	EF Arkansas River	Mitchell River Headwaters
Drainage Area	6.8	49.9	6.2
Valley Type	VII	V	VII
Stream Type	C4b	C4	B4
Wbkf (ft)	30.7	38.6	36.9
Abkf (ft^2)	57.4	66.7	75.5
WDR	18	22	18
D50	33	90	32
ER	2.8	2.9	1.95
Bank Erosion (ton/yr/ft)	0.0065	0.0045	0.0055
Slope (ft/ft)	0.023	0.018	0.025
Pool-Pool Spacing Ratio	6-8	5-6	1.5-3
MWR Ratio	9-12	10-12	4-6
BELT Ratio	3-6	4-7	2-4
ROC Ratio	2-4	2-5	2-4

Table – Conceptual Design Data for East Branch

Approximate Drainage Area (sq mi)	~7-9	~7-9	~7-9
Valley Type	East Branch 1	East Branch 1	East Branch 1
	UCV	**PCV**	**PCV**
Stream Type	C4 (Alluvial)	C4b (Alluvial)	B4 (Threshold)
Wbkf (ft)	28	25	28
Abkf (ft2)	36	35	36
Dbkf(ft)	1.27	1.39	1.27
WDR	22	18	22
D50 (mm)	90-100	120-140	180-200
Entrenchment Ratio	2.25	2.75	1.75
Bank Erosion (ton/yr/ft)	0.0055	0.0065	0.0025
Slope (ft/ft)	1%-2%	2%-3%	2%-4%
Pool-Pool Spacing Ratio	5.0-7.0	3.0 - 4.0	1.75-2.0
MWR Ratio (MWR * n/a for stream type)	4.0-7.0*	3.0-5.0*	1.25-1.75*
MLR Ratio (MLR * n/a for stream type)	8.0-10.0*	4.50-5.50	2.5-3.0*
Rc Ratio	3.0-4.5	2.5-4.0	3.5-5.0
K, Sinuosity	1.2	1.05	1.02
Applied Shear Stress (lbs/sqft)	1.6	2.6	4.0
Manning's "n"	0.045	0.045	0.065
Estimated Velocity (ft/s)	5.5	7.1	6.0
Unit Stream Power (ft-lbs/s-ft)	8.7	18.6	23.9

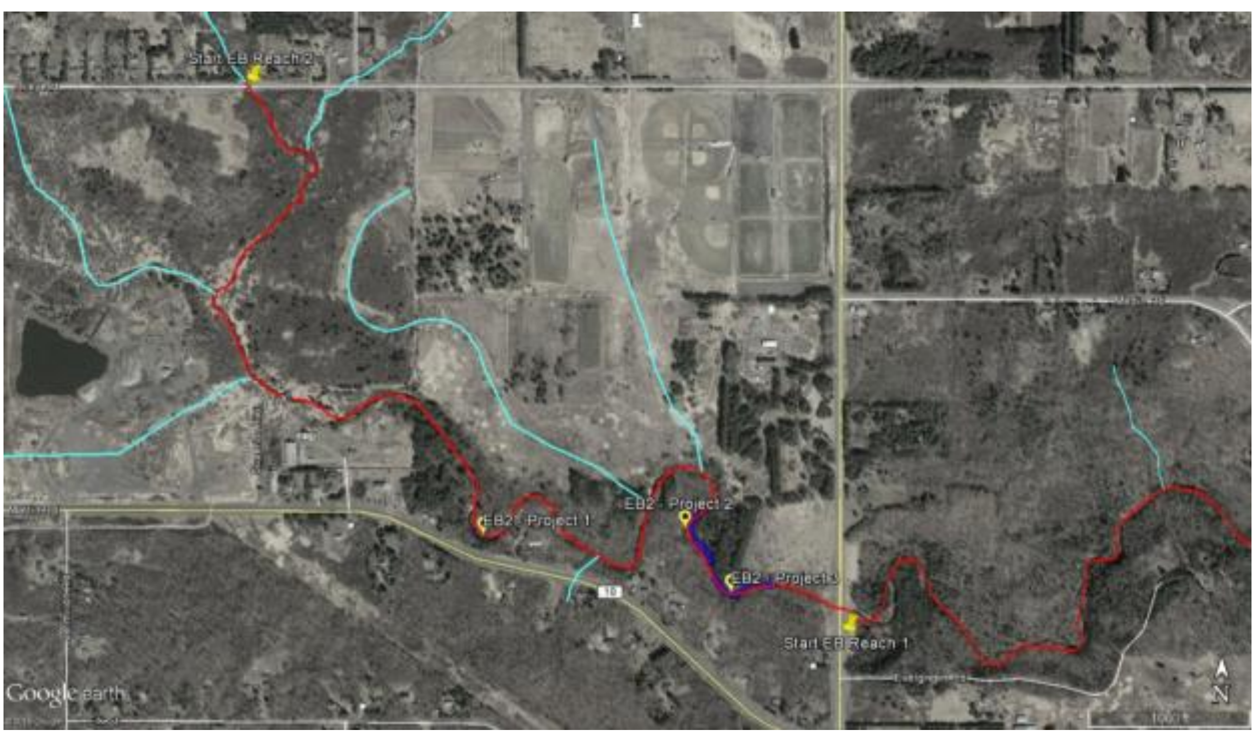
East Branch 2 (EB-2)

Channel Type:	C4
Potential Stream Type:	C4
Valley Type:	Partially Unconfined Valley
Concern Level:	High
Potential Projects:	3
Access:	Moderate/Good

East Branch Reach 2 was identified as a high priority and level of concern. Horizontal instability and migration was observed and documented through the reach. East Branch Reach 2 had very high terraces where the stream was cutting into causing large amounts of sediment to be added to the creek along with trees. The trees have created blockage that have caused high near bank shear stresses and movement in the channel. 3 projects were identified for this reach. Much of the identified projects are bank stabilization with some minor realignment in places. Poor habitat and vegetation in spots were noted. Access to the creek will be somewhat challenging as to the high valley walls but should be able to get to project site with an access road from the north property. Projects 2 and 3 could be combined into one project is funding is available. Post restoration would see results in 90-95% sediment reduction. There is no infrastructure in danger within the reach.

Total Restored Liner Foot:	1,060 ft
Cost of Restoration:	$330,000 - $435,000 ($311- $410 per/ft)

Geomorphic Stability:	Poor
Vegetation Condition:	Fair
Habitat Condition:	Fair



Assessment Forms for East Branch Reach 2 Projects

Stream: **East Branch**	Location: **Reach 1**
Observers: **MJG, GJ, JZ**	Date: **10/27/2015**; Stream Type: **C4**; Valley Type: **PUCV**
Channel Dimension	Mean Bankfull Depth (ft): **1.5**; Bankfull Width (ft): **~42**; Cross-Sectional Area (ft^2): **~55**; Width/Depth Ratio: **33**; Entrenchment Ratio: **<4.5**
Channel Pattern	Mean / Range: λ/W_{bkf}: **5** / **7**; L_m/W_{bkf}: **6** / **8**; R_c/W_{bkf}: **2** / **3**; MWR: **2.2** / **3.5**; Sinuosity: **1.2**
Streamflow	Bankfull Mean Velocity ($\bar{u}_{bkf}$) (ft/sec): **~4**; Bankfull Discharge (Q_{bkf}): **160**; Estimation Method: **Mannings**; Drainage Area (mi^2): **7.55**
River Profile & Bed Features	Check: ☑ Riffle/Pool ☐ Step/Pool ☐ Plane Bed ☐ Convergence/Divergence ☐ Dunes/Antidunes/Smooth Bed
	Max Bankfull Depth (ft): Riffle **3**, Pool **6**; Depth Ratio (max to mean): Riffle **2**, Pool **4**; Pool-to-Pool Spacing: Ratio **1.283**; Slope: Valley: **0.004**, Water Surface: **0.006**
Level III Stream Stability Indices	Riparian Vegetation: Current Composition/Density: **Cottenwood and Willow**; Potential Composition/Density: **Cottenwood and Willow**; Remarks: Condition, Vigor & Usage of Existing Reach: **not much tree veg**
	Flow Regime: **P2**; Stream Size & Order: **S4**; Meander Patterns: **M2,M3**; Depositional Patterns: **B2,B4**; Debris/Channel Blockages: **D2**
	Degree of Incision (Bank-Height Ratio): ; Degree of Incision Stability Rating: **Stable (not incised)**; Modified Pfankuch Stability Rating (Numeric & Adjective Rating): **N/A**
	Width/depth Ratio (W/d): **1.8**; Reference W/d Ratio (W/d_{ref}): **22**; Width/Depth Ratio State (W/d) / (W/d_{ref}): **1.60**; W/d Ratio State Stability Rating: **Highly Unstable**
	Meander Width Ratio (MWR): **3.5**; Reference MWR_{ref}: **3.8**; Degree of confinement (MWR / MWR_{ref}): **0.92105263**; MWR / MWR_{ref} Stability Rating: **Moderate Departure**
Bank Erosion Summary	Length of Reach Studied (ft): **1400**; Annual Streambank Erosion Rate: **112** (tons/yr) **0.186667** (tons/yr/ft); Curve Used: **COLORADO**; Remarks: **High Bank Erosion**
Sediment Capacity (POWERSED)	☐ Sufficient Capacity ☑ Insufficient Capacity ☐ Excess Capacity; Remarks: **Need Better W/D to Move**
Successional Stage Shift	**E** ⟶ **C** ⟶ **HighW/D C** ⟶ **F** ⟶ ⟶; Existing Stream State (Type): **C**; Potential Stream State (Type): **C**
Lateral Stability	☐ *Stable* ☐ *Mod. Unstable* ☐ *Unstable* ☑ *Highly Unstable*; Remarks/causes: **High Bank Eroison W/D State**
Vertical Stability (Aggradation)	☐ *No Deposition* ☑ *Mod. Deposition* ☐ *Ex. Deposition* ☐ *Aggradation*; Remarks/causes: **have slope and depth to move particles**
Vertical Stability (Degradation)	☐ *Not Incised* ☐ *Slightly Incised* ☐ *Mod. Incised* ☑ *Degradation*; Remarks/causes: **High Incision**
Channel Enlargement	☐ *No Increase* ☐ *Slight Increase* ☑ *Mod. Increase* ☐ *Extensive*; Remarks/causes: **Excpet to get wider over time**
Sediment Supply (Channel Source)	☐ *Low* ☐ *Moderate* ☐ *High* ☑ *Very High*; Remarks/causes: **Excess Sediment, Bank Failure, Head Cutting**

RAPID GEOMORPHIC ASSESSMENT					
Watercourse		East Branch	**Date:**		10/27/2016
Location		Duluth, MN	**Reach:**		Reach 1
Process (1)	GEOMORPHIC INDICATOR		PRESENT		FACTOR
	NO (2)	DESCRIPTION (3)	NO (4)	YES (5)	VALUE (6)
Evidence of Aggradation (AI)	1	Lobrate bar	x		
	2	Coarse Material in Riffle embedded		x	
	3	siltation in pools		x	
	4	medial bars		x	
	5	accreation on point bars			
	6	poor longitudinal sorting of bed materials		x	
	7	deposition in overbank zone		x	
		SUM OF INDICES	**1**	**5**	**0.83**
Evidence of Degradation (DI)	1	Exposed bridge footing	x		
	2	Exposed sanitary/storm sewer/pipeline ect..	x		
	3	Elevated Stormwater outfall(s)	x		
	4	undermined gabion baskets/concrete aprons/ect..	x	x	
	5	Scourpools d/s of culverts/stormwater outlets			
	6	Cur face on barm forms			
	7	Headcutting due to knick point migration		x	
	8	Terrace cut though older bar material		x	
	9	Suspended armour layer visible in bank		x	
	10	Channel worn into undisturbed overburden/bedrock		x	
		SUM OF INDICES	**4**	**5**	**0.56**
Evidence of Degradation (DI)	1	Fallen/leaning trees/fences posts ect.		x	
	2	Occurrence of Large Organic Debris		x	
	3	Exposed tree roots		x	
	4	basal scour inside meander bends		x	
	5	basal scour on both sides fo channel through riffle		x	
	6	gabion baskets/concrete walls/armor stone out flanked		x	
	7	Length of basal scour >50% though subject reach	x		
	8	Exposed length of previously burried piple cable/ect.	x		
	9	Fractur lines along top of bank	x		
	10	Exposed building foundation	x		
		SUM OF INDICES	**4**	**6**	**0.60**
Evidence of Aggradation (AI)	1	Formation of cute(s)	x		
	2	Evolution of single tread into multipile channel	x		
	3	Evolution of pool-riffle form to low bed felif form		x	
	4	Cutoff channel(s)	x		
	5	Formation of island(s)	x		
	6	Thalweg alignment out of phase with geometry		x	
	7	Bar forms poorly formed/reworked/removed		x	
		SUM OF INDICES	**4**	**3**	**0.43**
STABILITY INDEX (SI) = (AI +DI + WI + PI) / M					**0.60**

Stream Condition and Function: Score from 0 to 2 indicating natural stream integrity and health:
2 = Good; 1 = Fair; 0 = Poor

1. Upstream watershed impacts from stormwater, wastewater, or sediment ___1__

Good: no impacts from upstream sources	Fair: some minor impacts from upstream sources	Poor: major impacts from upstream sources

2. Local stream reach impacts from ditches, pipes, livestock, utilities, or roads ___2__

Good: no impacts from local sources	Fair: some minor impacts from local sources	Poor: major impacts from local sources

3. Channel dimension related to bankfull cross-section measurements ___1__

Good: natural equilibrium width, depth, and area dimensions expected for the watershed	Fair: some disequilibrium indicated by unnatural dimensions	Poor: major disequilibrium indicated by incision, widening, high variability, or channelized system

4. Channel pattern related to planform measurements __0___

Good: natural equilibrium meander pattern with sinuosity expected for the watershed	Fair: some disequilibrium indicated by unnatural pattern features	Poor: major disequilibrium indicated by tight bends, cutoffs, rapid down-valley meander migration, or straightening

5. Channel bed profile related to longitudinal profile measurements __1___

Good: natural equilibrium riffles, pools, steps, glides, and runs with bedform expected for the watershed	Fair: some disequilibrium indicated by unnatural or missing bedform features	Poor: major disequilibrium indicated by head cutting, plane bed, aggradation, or riffle migration into pools

6. Streambank stability and protection from erosion __0___

Good: low erodibility resulting from covered soil, low banks, deep roots, low stress	Fair: moderate erodibility resulting from some bare soil or erodible bank conditions	Poor: high erodibility resulting from bare soil, eroding bends, steep banks, high banks, lack of roots, high stress

7. Floodplain connection for bankfull flood access ___1__

Good: regular floodplain access with BHR < 1.2	Fair: some incision with BHR = 1.2–1.9	Poor: severely incised channel with BHR > 2

8. Floodplain morphology to dissipate flood energy and minimize erosion __1___

Good: low entrenchment with ER > 5 and no contractions	Fair: moderate entrenchment with ER = 1.5–5 and/or minor contractions	Poor: severe entrenchment with ER < 1.5 and/or major contractions

9. Riparian vegetation to provide shade, nutrient uptake, and food sources __1.5__

Good: healthy native plants growing in more than 90% of 50-ft buffer on both sides	Fair: healthy native plants growing in half to 90% of 50-ft buffer on both sides	Poor: healthy native plants growing in less than half of 50-ft buffer on both sides

10. Habitats including diverse bedform, large woody debris, leaf packs, root hairs __1___

Good: healthy aquatic micro- and macro-habitat features expected for watershed	Fair: lacking up to half of expected aquatic habitat features	Poor: lacking more than half of expected aquatic habitat features

11. Water quality and stream bed sediments __2___

Good: clear water with natural sediments expected for watershed	Fair: some turbidity and/or embeddedness affecting habitat conditions	Poor: excessive turbidity and/or embeddedness strongly affecting habitat conditions

12. Presence of desirable fish and macroinvertebrates expected for watershed __2___

Good: healthy communities including intolerant taxa	Fair: missing some intolerant taxa	Poor: lacking expected communities and/or dominated by tolerant taxa

Notes: _Poor Geomorphic Conditions with some Fair components. Major re-alignment is needed to fix most of this reach. Bank erosion is high.

Project Site 1 –Bank Stabilization

Location:
Latitude: 46°51'54.28"N
Longitude: 92° 3'24.74"W

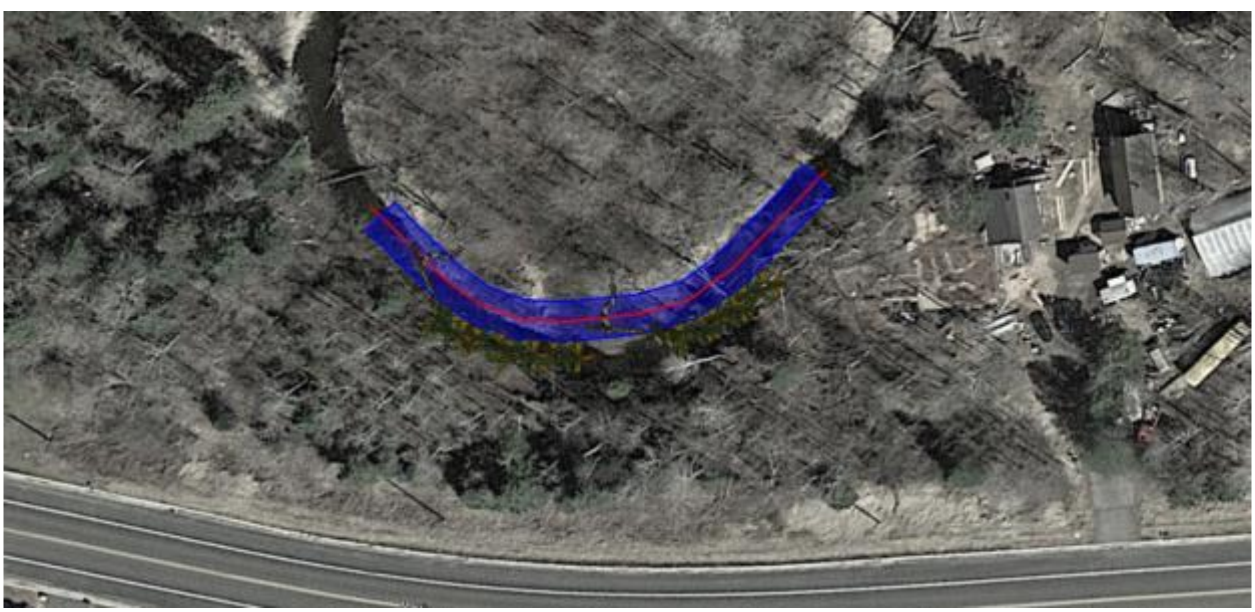
Length:
Existing: 200 ft
Proposed: 200 ft

Existing Conditions:
- Bank Erosion
- High NBS
- Large Terrace Wall

Restoration Options:
- Bank Stabilization/Toe Wood
- Log Vanes to deflect water
- Re-use boulders for toe protection

Restoration Objectives:
- Provide more floodplain to reduce stress
- Reduce Bank Erosion

Cost Estimate:
- ~$75,000-$125,000



Project Site 2 – Stream Re-Alignment / Bank Stabilization, Priority 2 Restoration

Location:

Latitude: 46°51'54.80"N
Longitude: 92° 3'6.58"W

Length:

Existing: 475 ft
Proposed: 420 ft

Existing Conditions:

- High eroding terrace wall
- Very high NBS
- High BHR
-

Restoration Options:

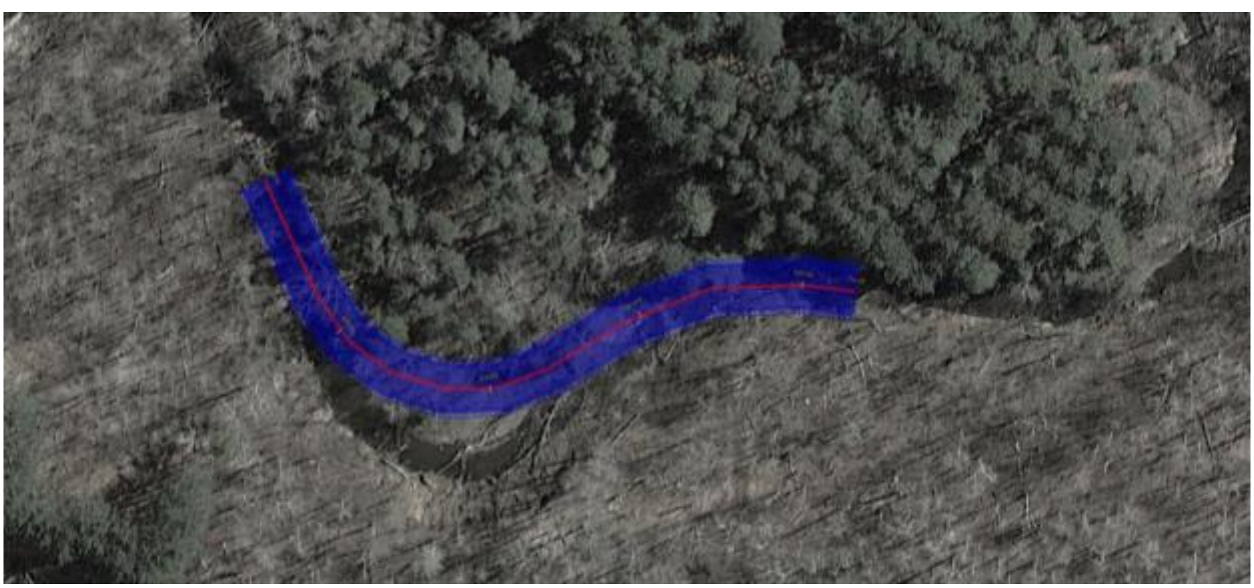
- Priority 2 Restoration
- Establish Floodplain Bench
- Use of Toe Wood, Natural Constructed Riffles, Log Vanes

Restoration Objectives:

- Move creek away from terrace wall
- Establish floodplain bench

Cost Estimate:

- ~$125,000-$150,000



Project Site 3 – Stream Re-Alignment / Bank Stabilization, Priority 2 Restoration

Location:

Latitude: 46°51'50.89"N
Longitude: 92° 3'2.41"W

Length:

Existing: 475 ft
Proposed: 440 ft

Existing Conditions:

- High Terrace Bank Erosion
- Very High NBS
- Active Head Cut
- Lots of fallen trees

Restoration Options:

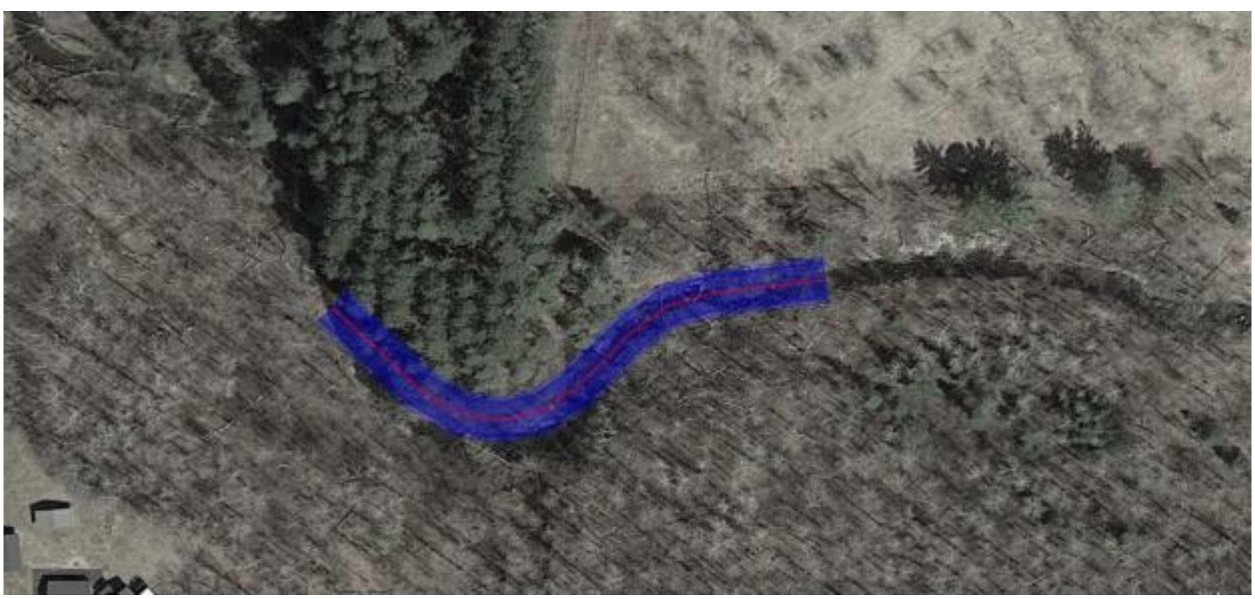
- Priority 2 Restoration
- Create Floodplain Bench
- Grade Control Structure
- Use of Toe Wood, Natural Constructed Riffles, boulder clusters

Restoration Objectives:

- Reduce NBS, Bank Erosion
- Prevent Head Cut
- Move away from terrace walls

Cost Estimate:

- ~$130,000 – $160,000



Conceptual Design Data for East Branch Reach 2 Projects

Table - East Branch Reference Reaches

Reach	Basin Creek	EF Arkansas River	Mitchell River Headwaters
Drainage Area	6.8	49.9	6.2
Valley Type	VII	V	VII
Stream Type	C4b	C4	B4
Wbkf (ft)	30.7	38.6	36.9
Abkf (ft^2)	57.4	66.7	75.5
WDR	18	22	18
D50	33	90	32
ER	2.8	2.9	1.95
Bank Erosion (ton/yr/ft)	0.0065	0.0045	0.0055
Slope (ft/ft)	0.023	0.018	0.025
Pool-Pool Spacing Ratio	6-8	5-6	1.5-3
MWR Ratio	9-12	10-12	4-6
BELT Ratio	3-6	4-7	2-4
ROC Ratio	2-4	2-5	2-4

Table – Conceptual Design Data for East Branch

Approximate Drainage Area (sq miles)	~7-9	~7-9	~7-9
Valley Type	East Branch 2	East Branch 2	East Branch 2
	UCV	**PCV**	**PCV**
Stream Type	C4 (Alluvial)	C4b (Alluvial)	B4 (Threshold)
Wbkf (ft)	28	25	28
Abkf (ft2)	36	35	36
Dbkf(ft)	1.27	1.39	1.27
WDR	22	18	22
D50 (mm)	90-100	120-140	180-200
Entrenchment Ratio	2.25	2.75	1.75
Bank Erosion (ton/yr/ft)	0.0055	0.0065	0.0025
Slope (ft/ft)	1%-2%	2%-3%	2%-4%
Pool-Pool Spacing Ratio	5.0-7.0	3.0 - 4.0	1.75-2.0
MWR Ratio (MWR * n/a for stream type)	4.0-7.0*	3.0-5.0*	1.25-1.75*
MLR Ratio (MLR * n/a for stream type)	8.0-10.0*	4.50-5.50	2.5-3.0*
Rc Ratio	3.0-4.5	2.5-4.0	3.5-5.0
K, Sinuosity	1.2	1.05	1.02
Applied Shear Stress (lbs/sqft)	1.6	2.6	4.0
Manning's "n"	0.045	0.045	0.065
Estimated Velocity (ft/s)	5.5	7.1	6.0
Unit Stream Power (ft-lbs/s-ft)	8.7	18.6	23.9

Amity Creek Supplemental Data (2017) - Appendix B

Duluth WRAPS

Prepared by South St. Louis Soil and Water Conservation District (SWCD)
2016/2017

Amity Creek Watershed

Recommendations

Road Crossing Replacement, Removal, or Repair

These road crossings are the highest priority crossings recommended for replacement, removal, or repair in the Amity Creek watershed.

Street Name
Mainstem—Woodland Avenue
East Amity—West Tischer Road
Mainstem--Seven Bridges Road, 3rd bridge
Mainstem—Nelson Road
Mainstem—Jean Duluth Road
Mainstem—Thomas Road
East Amity—Arnold Road

Additional Data Sources

USGS

The United States Geological Survey (USGS) assessed Duluth's streams in 2006 in an attempt to characterize and classify them. Following an estimated 500 year flood in June of 2012, it was decided that the 2006 sites would be reassessed to observe the impact the flood had on these reaches. This data was also used to determine the sensitivity to disturbance for reaches within all the major watersheds in Duluth. The downstream section of Amity Creek, in the Seven Bridges Road area, is identified as low sensitivity. The mid sections of both the main stem and East Amity are high to moderate, and high sensitivity. The most upstream section of East Amity has high sensitivity, while the most upstream section of the main stem has moderate to low sensitivity. Many intensive surveys and rapid assessments were completed by the USGS on Amity Creek.

USGS site Name	Assessment Type	Location
11	Intensive	Occidental Road, Lester Park
12	Rapid	Occidental Road, Amity Creek Park, #1
13	Rapid	Occidental Road, Amity Creek Park, #2
14	Rapid	Occidental Road, Amity Creek Park, #3
15	Rapid	Occidental Road, Amity Creek Park, #4
16	Rapid	Occidental Road, Amity Creek Park, #5
17	Rapid	Occidental Road, Amity Creek Park, #6
18	Rapid	Skyline Road

Minnesota Department of Natural Resources Fisheries Management Plan

Amity Creek is a designated trout stream. Both steelhead/rainbow trout and brook trout are present in the stream the steelhead migrate into the stream from Lake Superior and can only go upstream as far as the most downstream bedrock waterfall, barrier. Steelhead fry are stocked annually off of Seven Bridges Road. Brook trout are located in the upper watershed. Currently no brook trout stocking is occurring. In the past brown trout were also stocked in Amity Creek. This occurred from 1955 to 1971. The DNR fisheries management plan states the goals of providing steelhead nursery habitat, maintaining current brook trout populations, mitigating erosion, and reestablishing vegetation as goals for the watershed.

Watershed Results

Connectivity

Stream Road Crossings

Twenty nine road crossings exist within the Amity Creek watershed (Figure 1). 45 percent of these crossings are identified as barriers based on phase 1 of the Stream Crossing Prioritization Matrix. And 24 percent of the barriers are of high priority for replacement, removal, or repair. The Amity Creek watershed has the lowest number of road crossings per stream mile (1.1) and lowest number of road crossings acting as barriers per stream mile (0.5). Two crossings in Amity are included in the five highest priority stream road crossings for replacement, removal, or repair within the six study watersheds in Duluth (Keene, Merritt, Miller, Chester, Tischer, and Amity). These crossings include the Woodland Avenue crossing on the mainstem and the West Tischer Road crossing on the East Branch. The Woodland Avenue crossing is very narrow (half the width of the stream channel). This narrow width causes high velocities in the culvert during high flows. Fish cannot swim through these high velocities and the crossing is a barrier. The five highest priority road crossings for replacement, removal, or repair within the Amity Creek watershed are spread throughout the watershed and are located on both the mainstem and East Amity (Table 1).

Table 1. The highest priority road crossings within the Amity Creek watershed.

Street Name	Score
Mainstem—Woodland Avenue	160
East Amity—West Tischer Road	165
Mainstem--Seven Bridges Road, 3rd bridge	180
Mainstem—Nelson Road	240
Mainstem—Jean Duluth Road	240
Mainstem—Thomas Road	240
East Amity—Arnold Road	240

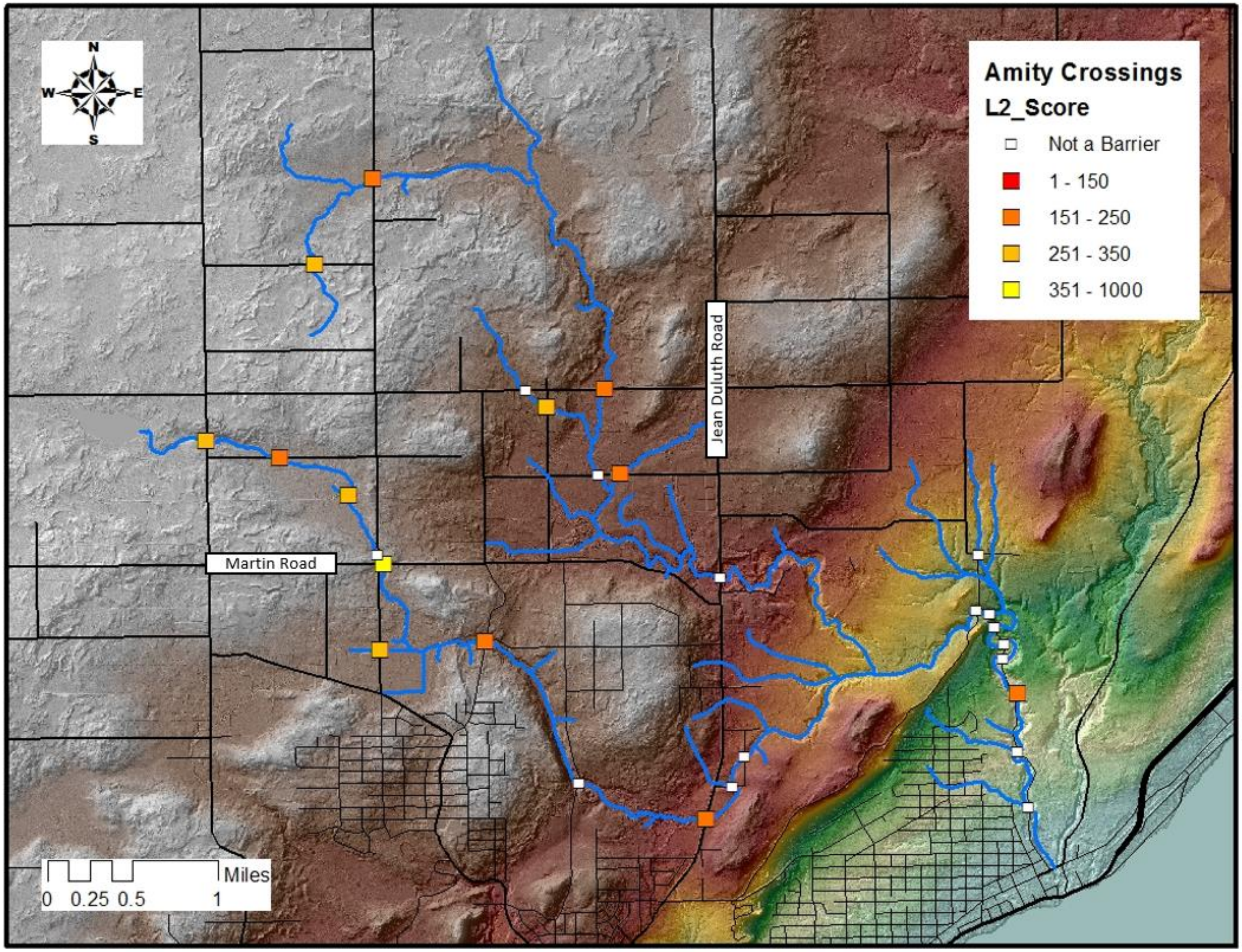


Figure 1. Road crossings within the Amity Creek watershed.

Appendix C – MS4 Regulated Areas

MS4 regulated area (NPDES/SDS permit ID)	Impairment subwatershed	MS4 Area (Acres)[b]
Duluth City MS4 (MS400086)[a]	Amity Creek	644
	Chester Creek	1,209
	East Branch Amity Creek	102
	Keene Creek	557
	Kingsbury Creek	256
	Lester River	707
	Unnamed Creek (Merritt Creek)	414
	Miller Creek	1,934
	Sargent Creek	142
	Stewart Creek	96
	Tischer Creek	1,230
Hermantown City MS4 (MS400093)[a]	Keene Creek	375
	Kingsbury Creek	239
	Unnamed Creek (Merritt Creek)	37
	Miller Creek	592
Midway Township MS4 (MS400146)[a]	Kingsbury Creek	142
	Sargent Creek	38
	Stewart Creek	16
Proctor City MS4 (MS400114)[a]	Kingsbury Creek	583
	Stewart Creek	5
Rice Lake City MS4 (MS400151)[a]	Amity Creek	589
	Chester Creek	12
	East Branch Amity Creek	378
	Lester River	778
	Miller Creek	49
	Tischer Creek	325
University of Minnesota, Duluth (MS400214)[a]	Chester Creek	0.5
	Lester River	0.1
	Miller Creek	7
	Tischer Creek	71
Lake Superior College (MS400225)[a]	Miller Creek	27
St. Louis County MS4 (MS400158)	Amity Creek	27

MS4 regulated area (NPDES/SDS permit ID)	Impairment subwatershed	MS4 Area (Acres)[b]
	Chester Creek	31
	East Branch Amity Creek	8
	Keene Creek	47
	Kingsbury Creek	71
	Lester River	27
	Unnamed Creek (Merritt Creek)	28
	Miller Creek	81
	Tischer Creek	69
MnDOT Outstate District MS4 (MS400180)	Chester Creek	1
	Keene Creek	58
	Kingsbury Creek	84
	Lester River	0.7
	Unnamed Creek (Merritt Creek)	24
	Miller Creek	152
	Sargent Creek	8
	Stewart Creek	13
	Tischer Creek	1

a. Regulated MS4 area represented by developed lands.

b. MS4 regulated areas rounded to nearest acre whenever possible.

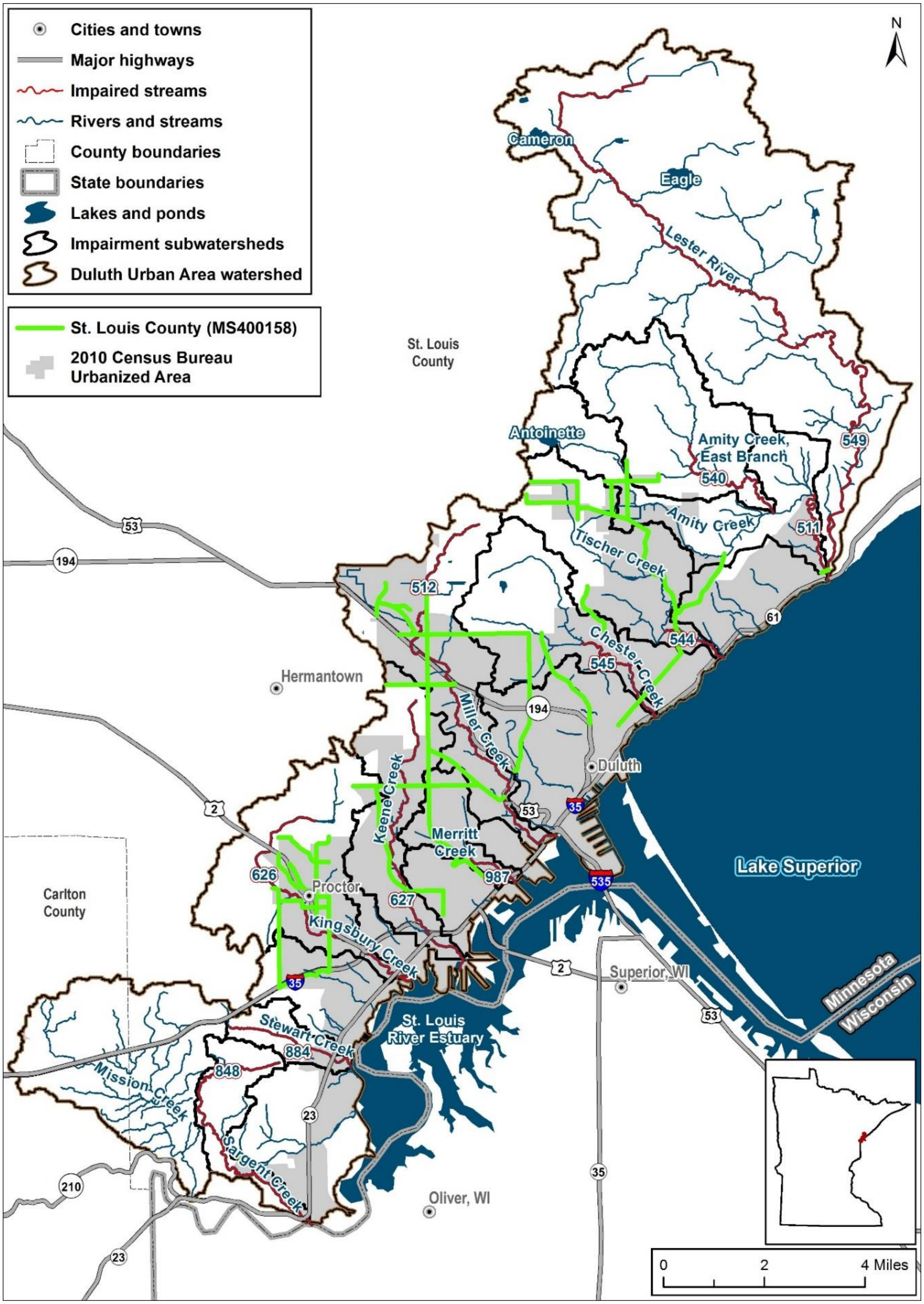


Figure 81. St. Louis County MS4.

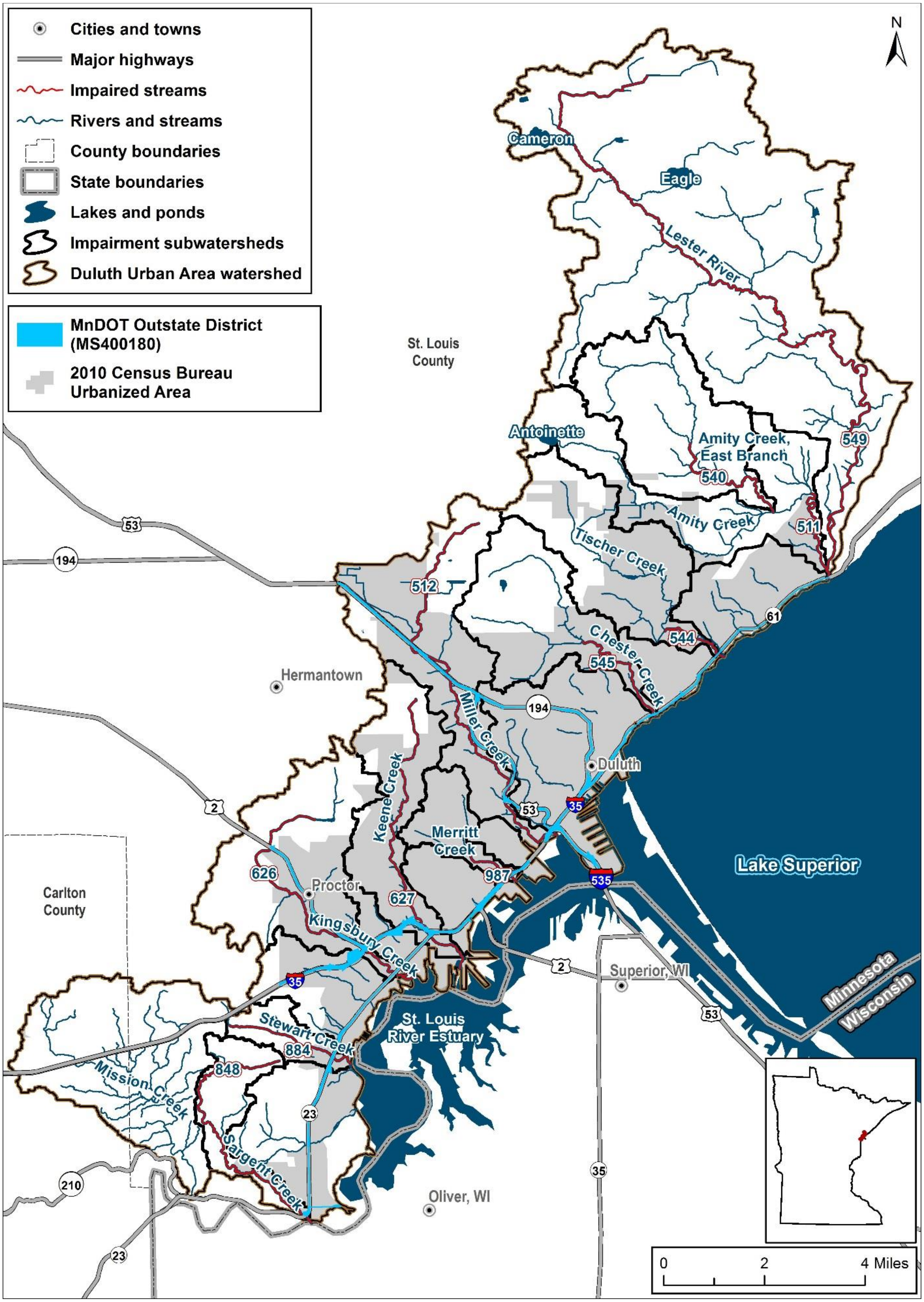


Figure 82. MnDOT Outstate District MS4.

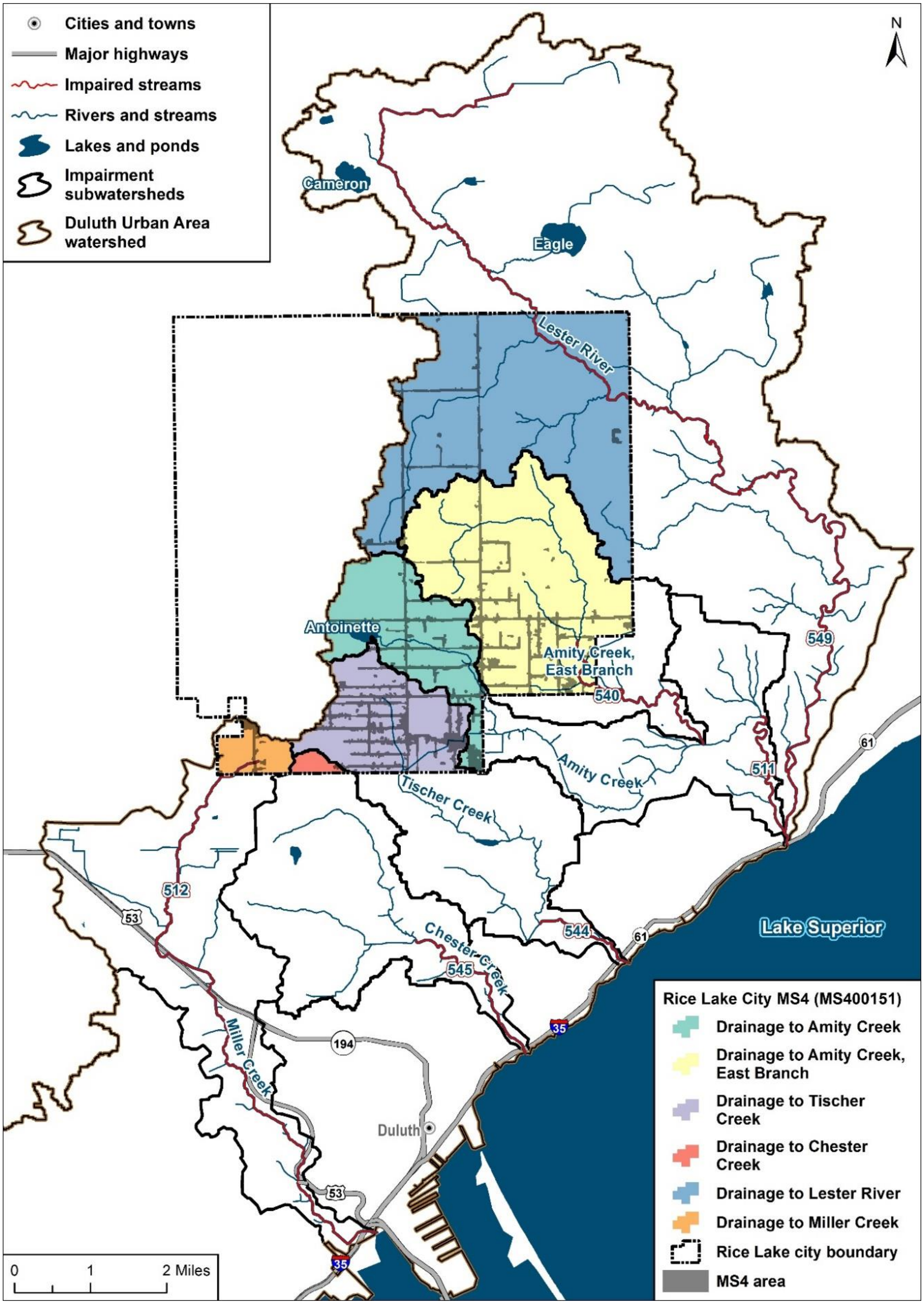


Figure 83. Rice Lake MS4.

The MS4 area does not include MS4 areas designated to MnDOT, St. Louis County, University of Minnesota, or Lake Superior College.

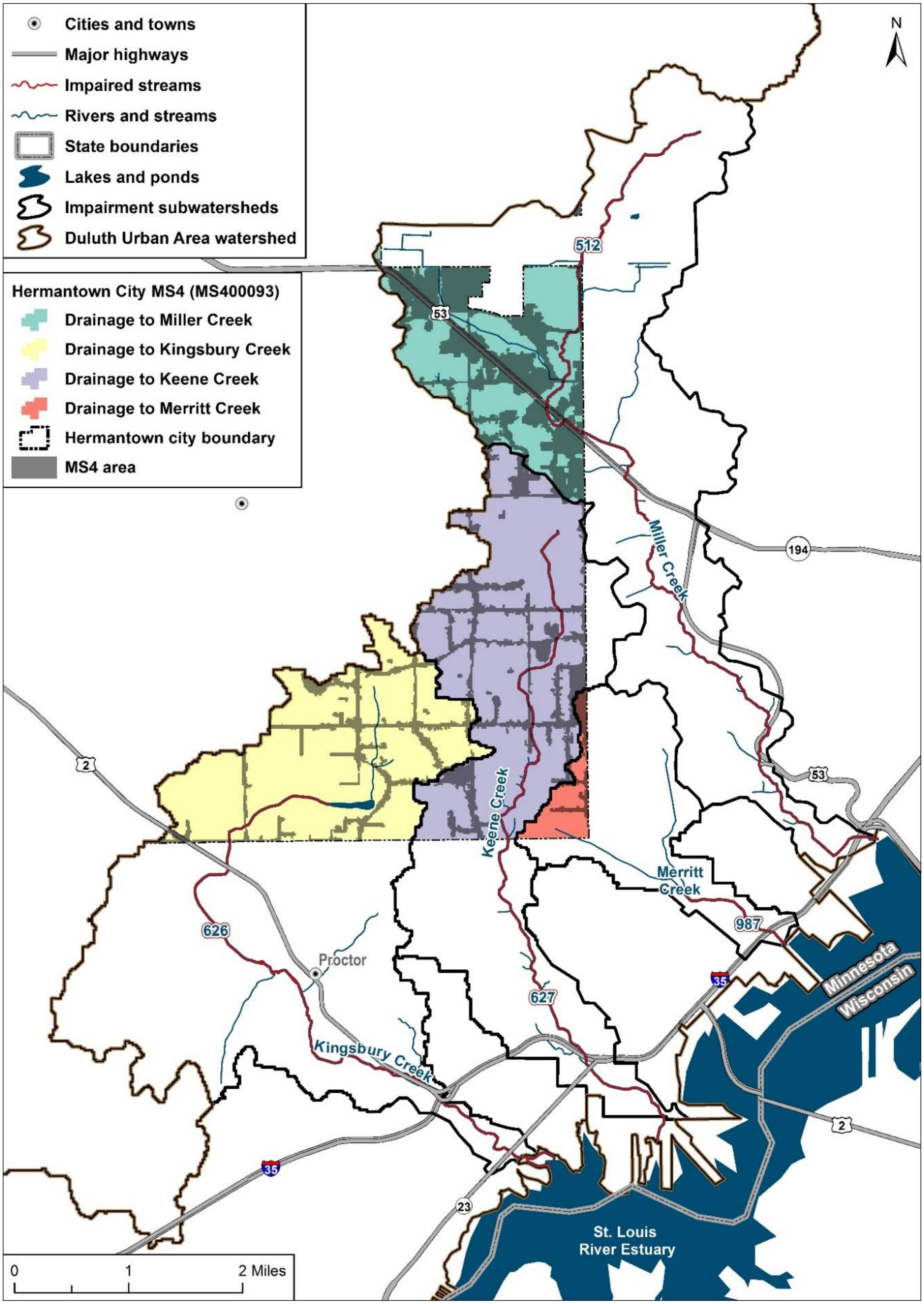


Figure 84. Hermantown MS4.

The MS4 area does not include MS4 areas designated to MnDOT, St. Louis County, University of Minnesota, or Lake Superior College.

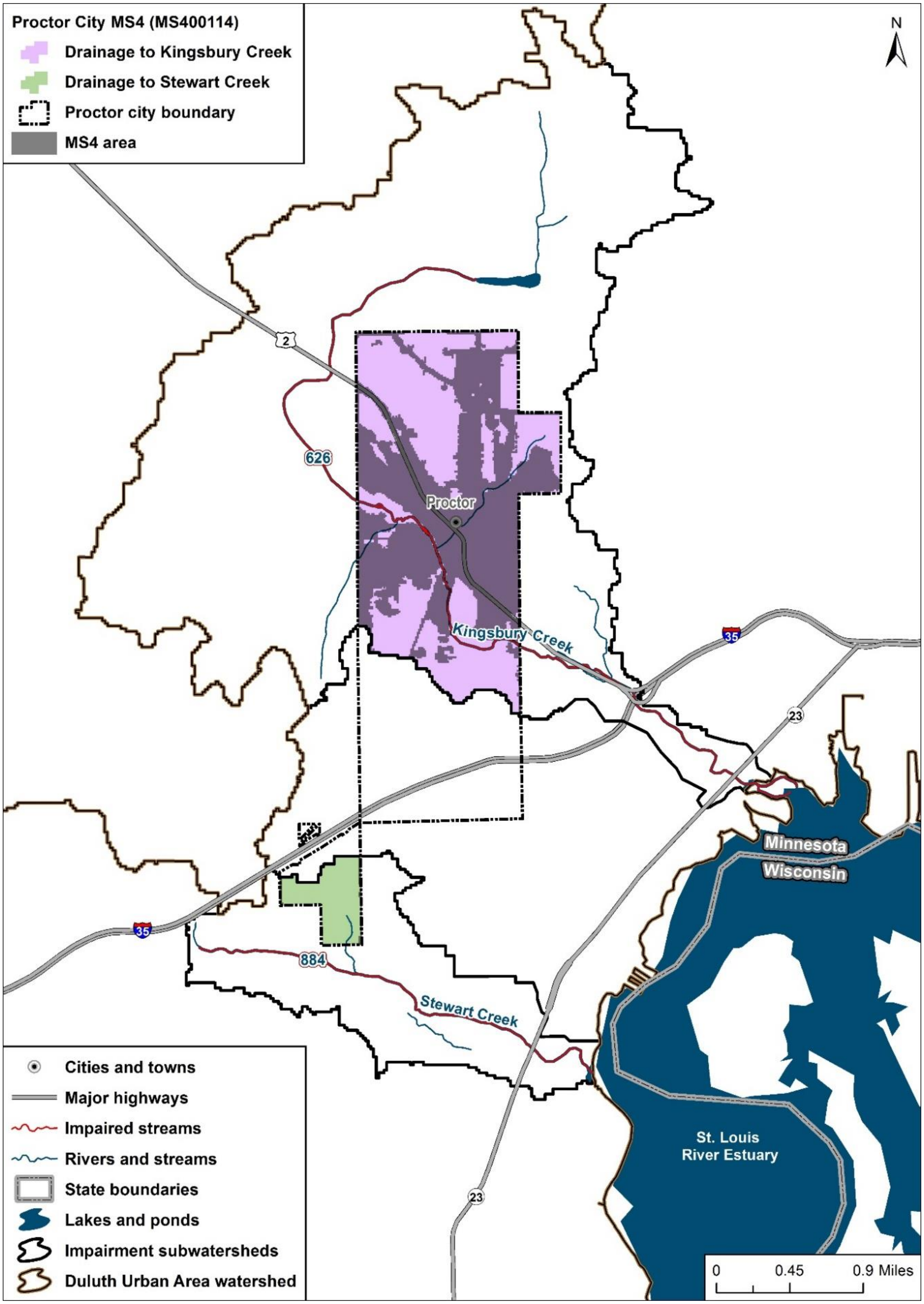


Figure 85. Proctor MS4.

The MS4 area does not include MS4 areas designated to MnDOT, St. Louis County, University of Minnesota, or Lake Superior College.

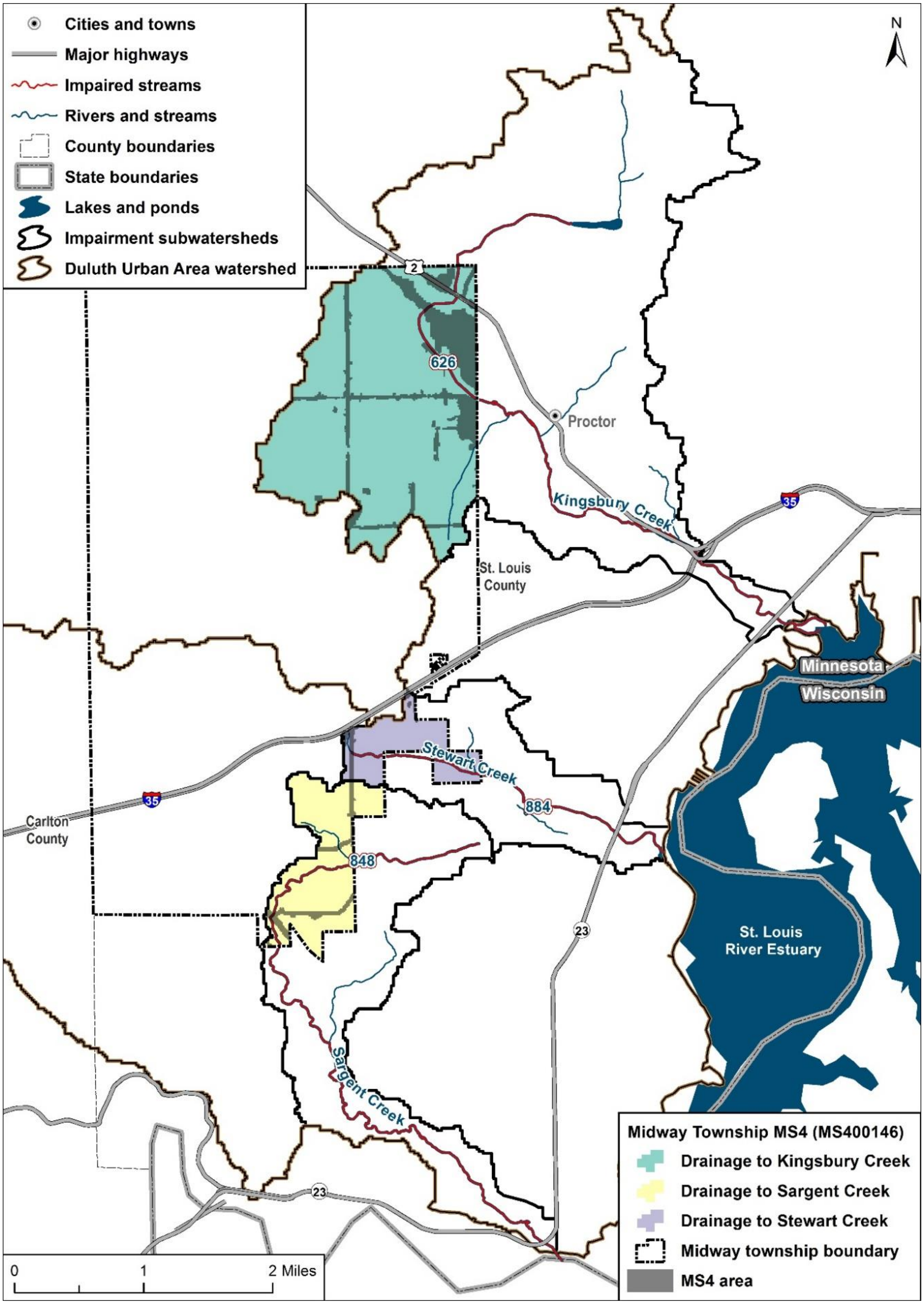


Figure 86. Midway Township MS4.

The MS4 area does not include MS4 areas designated to MnDOT, St. Louis County, University of Minnesota, or Lake Superior College.

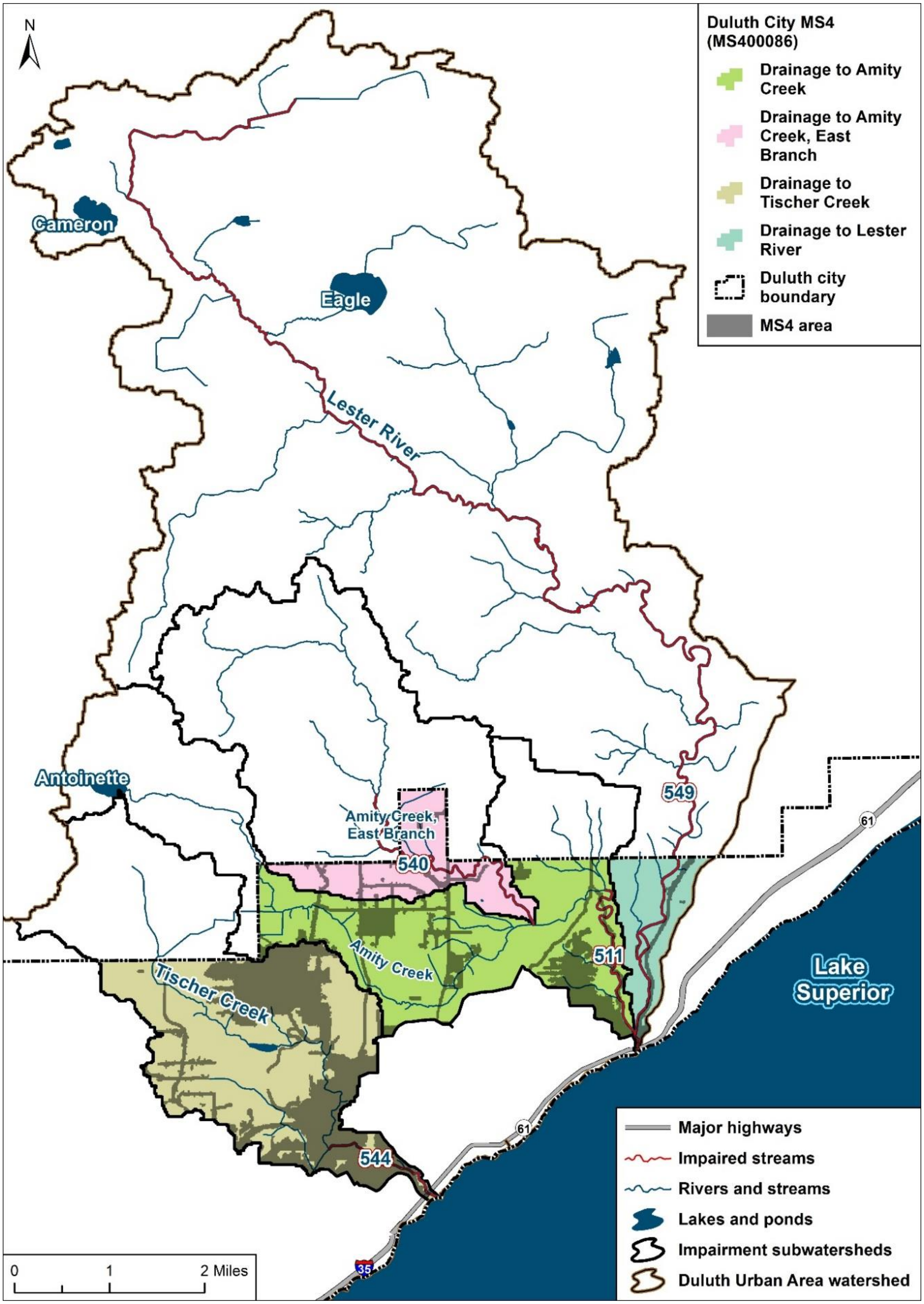


Figure 87. Duluth MS4 (northern).

The MS4 area does not include MS4 areas designated to MnDOT, St. Louis County, University of Minnesota, or Lake Superior College.

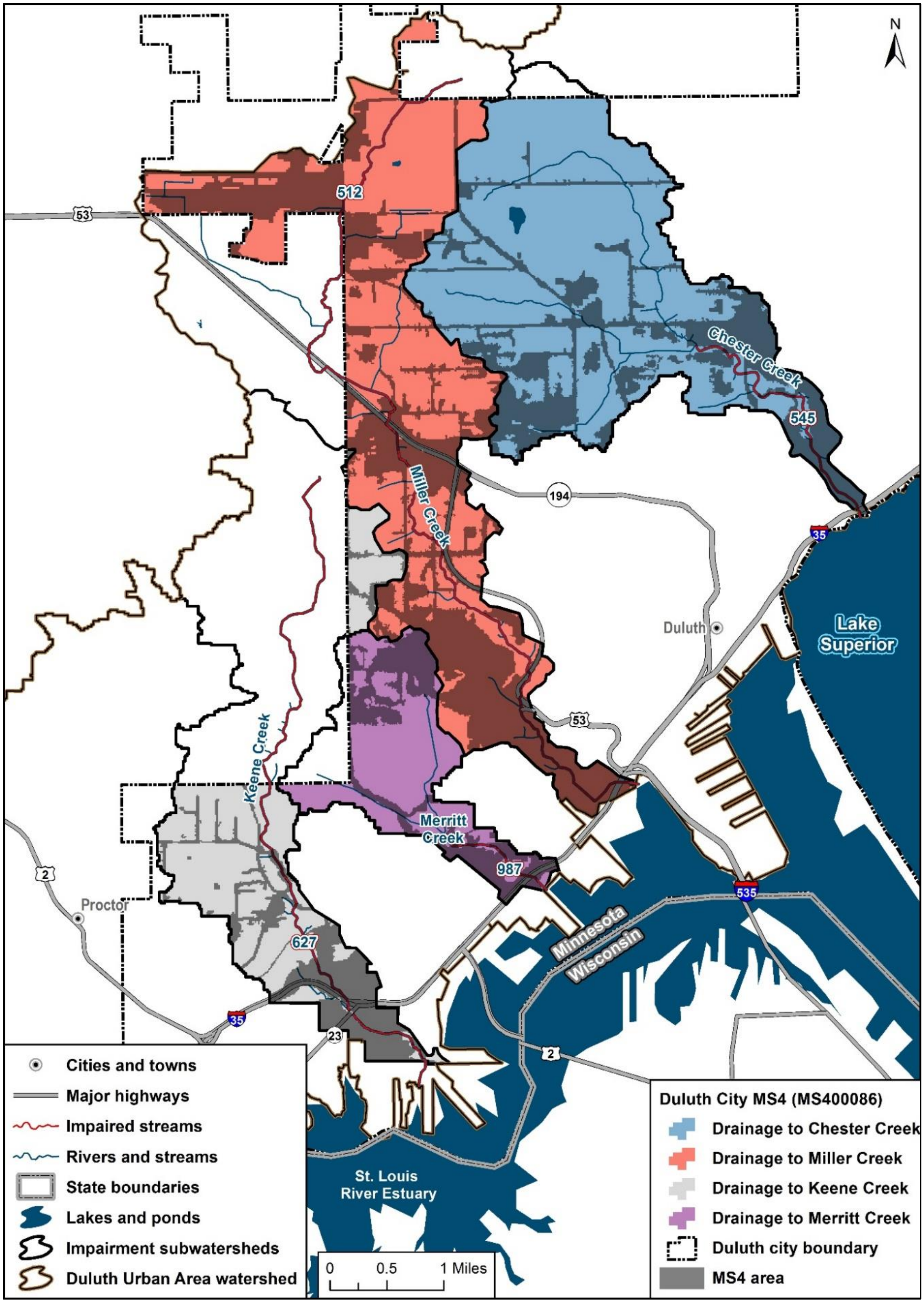


Figure 88. Duluth MS4 (middle).

The MS4 area does not include MS4 areas designated to MnDOT, St. Louis County, University of Minnesota, or Lake Superior College.

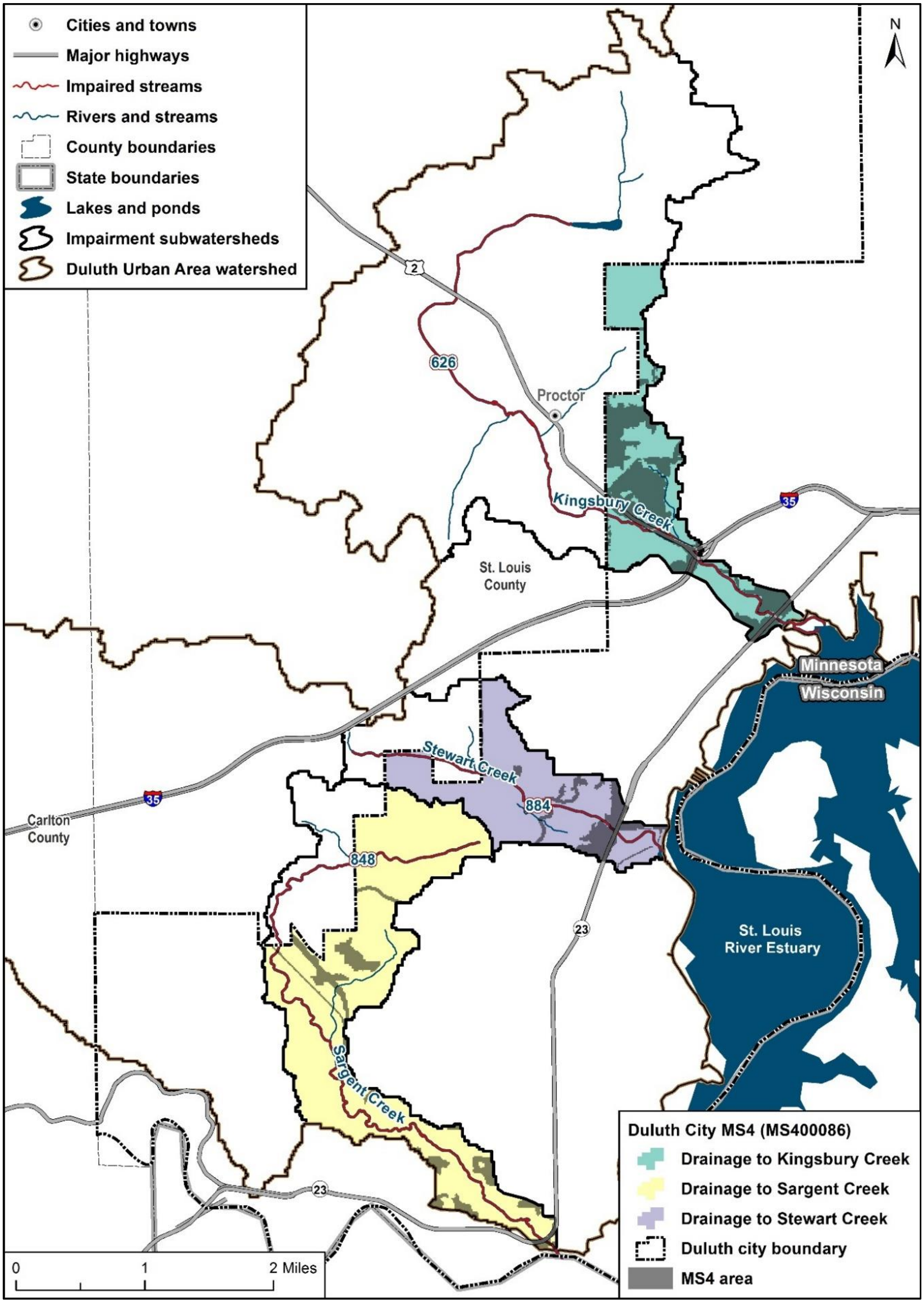


Figure 89. Duluth MS4 (southern).

The MS4 area does not include MS4 areas designated to MnDOT, St. Louis County, University of Minnesota, or Lake Superior College.

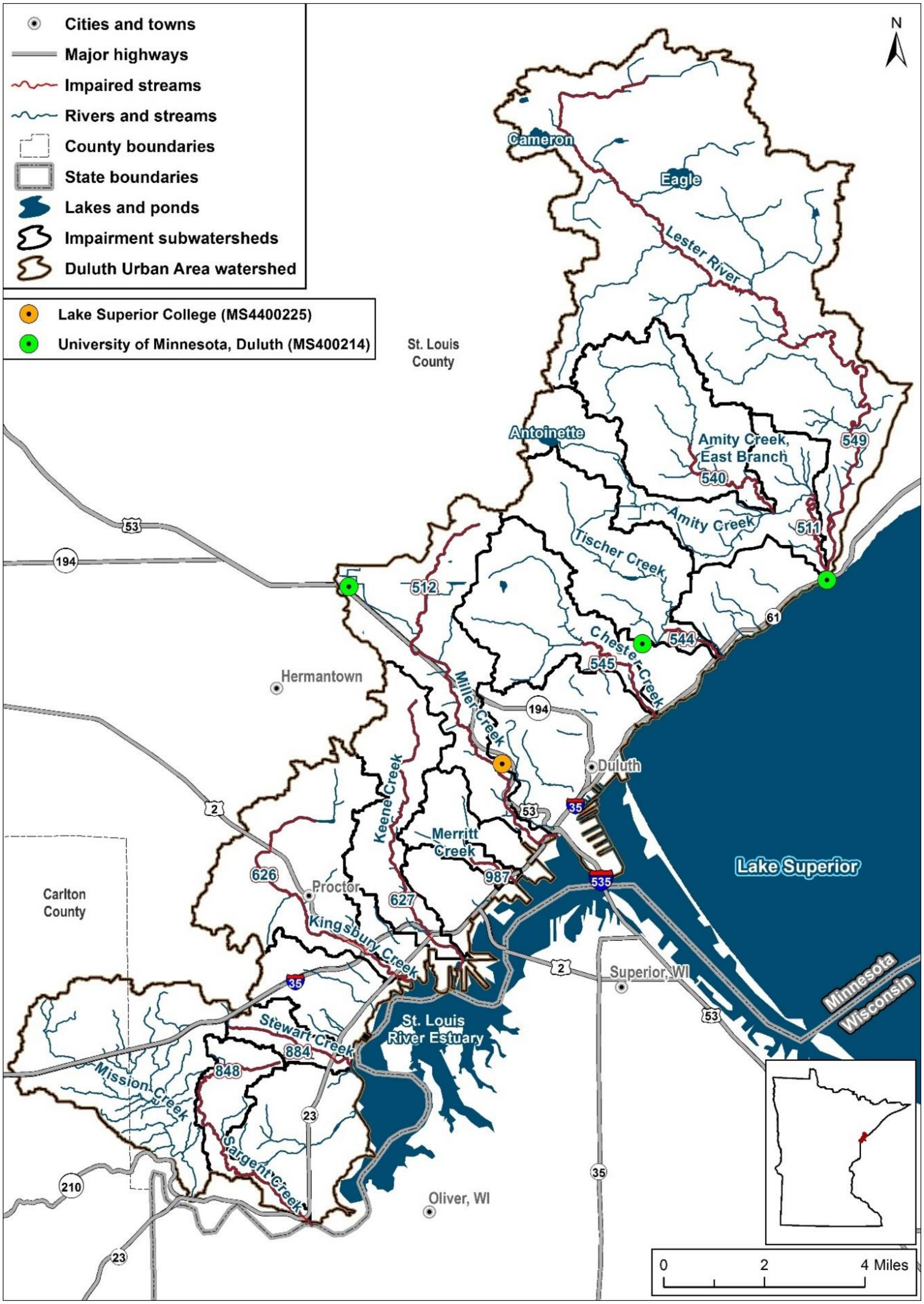


Figure 90. University of Minnesota and Lake Superior College MS4s.

Dots represent locations of regulated MS4 areas.